March 2007

FEASIBILITY OF GREEN DESIGN FOR WPI LIFE SCIENCES & BIOENGINEERING CENTER

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Project No. GFS - 0702
LDA - 0706

FEASIBILITY OF GREEN DESIGN FOR WPI LIFE SCIENCES & BIOENGINEERING CENTER

A Major Qualifying Project Report:

submitted to the Faculty

of the

WORCESTER POLYTECHNIC INSTITUTE

in partial fulfillment of the requirements for the

Degree of Bachelor of Science

by

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Date: March 1, 2007

Approved:

Keywords:
1. LEED Certification
2. Green Building
3. Cost Analysis
4. Roof Design

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ABSTRACT

This project developed an alternate roof design for WPI's Life Sciences & Engineering Center at Gateway Park to meet the LEED Heat Island Effect criteria, to reduce temperature differences between rural and urban areas. This steel roof design was developed using the LFRD and AISC methods, as well as the Massachusetts State Building Code. The project also investigated the cost and feasibility of meeting LEED Materials and Resources standards to promote sustainability in the construction industry.

AUTHORSHIP

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ACKNOWLEDGEMENTS

We would like to acknowledge all who helped us complete our project. We would especially like to thank our advisors, Professor Leonard Albano and Professor Guillermo Salazar for their help and guidance. We would like to thank the Consigli construction management team at Gateway Park, including Brian Hamilton and Steve Johnson, for allowing us to attend the owner/architect meetings and providing us with information vital to our project. We would like to acknowledge John Miller, Director of the Physical Plant, for providing us with information about WPI's current expansion projects. We would also like to thank Judith Nitsch, President of Nitsch Engineering and a member of the WPI Board of Trustees, for the information she shared with us on green building and current policies at WPI.

CAPSTONE DESIGN

In order to meet the capstone design requirement of this project, we redesigned the roof of the WPI Life Sciences & Bioengineering Center at Gateway Park to meet the roof Heat Island Effect criteria for LEED standards. We also determined the cost of building the Bioengineering Center to meet the Materials and Resources category of the LEED New Construction standards.

Meeting the Heat Island Effect criteria helps to reduce the low-scale temperature differences between rural and urban areas. The first step of redesigning the roof was to complete a structural analysis of the existing roof which prepared us to design an alternative sloped roof. This required giving special consideration to the roof's existing mechanical systems and accounting for the weight of our specifically selected solar reflective material. Additionally, local building codes were referenced in determining the loads the roof is required to bear.

Meeting the Materials and Resources category of the LEED certification criteria helps to promote sustainability within the construction industry. To determine the cost of meeting the criteria laid out in this category, we estimated the cost of the completed construction and then estimated the potential cost of the project had it been built to the LEED Materials and Resources standards.

This project addresses economic, environmental, sustainability, manufacturability, and health and safety constraints. We analyzed the costs and benefits of building the WPI Life Sciences & Bioengineering Center to LEED standards to determine if it would be economically feasible. Additionally, the new roof design addressed environmental and sustainability issues through reducing the building's energy usage and contribution to increased temperatures in urban areas. In terms of manufacturability, our roof design includes materials that are available regionally and can be assembled using standard construction methods. The design addresses health and safety constraints by meeting the Massachusetts Building Code and lessening the impact of the heat island effect created by the city.

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1.0 INTRODUCTION

On March 29, 2005, a $2.5 million grant from the U.S. Economic Development Administration was secured for the development and construction of Gateway Research Park in Worcester, Massachusetts. Built on eleven acres of redeveloped brownfields land, the focal point of this project has become the newly constructed WPI Life Sciences and Bioengineering Center. At a cost of approximately $30 million, the Center includes 124,600 square feet of space on four floors at 60/68 Prescott Street. Designed by Tsoi/Kobus Associates and built by Consigli Construction Co. of Milford, MA, the facility has entered its final stages of construction and will soon be occupied by WPI's Bioengineering Institute. The facility will house many graduate research programs along with outside tenants from the life sciences field. Though the building site was cleaned up using the appropriate methods for brownfields sites, it is important to note that the actual design and construction of the building was not aimed at meeting any environmental construction standard (Worcester Polytechnic Institute 1).

Building green can help the environment, the economy and the health of the community. According to the U.S. Green Building Council, "in the United States, buildings account for 36% of total energy usage, 65% of electricity consumption, 30% of greenhouse gas emissions, 30% of raw material use, 30% of waste output and 12% of potable water consumption." Some examples of the benefits of building green are protecting ecosystems and natural resources, reducing waste and operating expenses, and improving the quality of air and water.

The Leadership in Energy and Environmental Design (LEED) standard is a rating system designed to define the term "green building" in a quantitative way by establishing a common measurement universal to all green construction. Standards such as LEED help to ensure that construction methods maintain a minimum degree of sustainability in order to preserve the environment for future generations (U.S. Green Building Council).

This project aims to promote sustainability by showing the economic feasibility of green design, and has two separate but interrelated goals. The first goal is to redesign the roof of the WPI Life Sciences and Bioengineering Center to meet the roof Heat Island Effect criteria in the Sustainable Sites section of the LEED New Construction Standard. The second goal is to determine the feasibility of meeting the LEED certification criteria within the Materials and Resources category.

In order to reach these goals, we examined different aspects of the building and its construction. We carried out an analysis of the existing roof construction and designed a new roof to meet LEED Heat Island Effect criteria using the engineering techniques acquired through coursework at WPI. Simultaneously, we analyzed the materials and resources used in the actual construction of the building and compared them to the materials and resources that would have been required to comply with Materials and Resources LEED criteria. Our cost, design and specification information was obtained from Consigli Construction Co., RSMeans Cost Estimating guides, and archival research. A complete list of sources can be found in the bibliography.

2.0 LITERATURE REVIEW

In order to meet our first goal of designing a roof to meet the LEED Heat Island Effect specification, we needed to have an understanding of the heat island effect and the concept of the solar reflectance index (SRI). Additionally, we studied LEED certified projects that have met the Heat Island Effect criteria to serve as examples for the alternative roof design. To accomplish our second goal of developing a cost comparison of the actual construction and of construction to the LEED standards in the Materials and Resources category, it was important to develop a thorough understanding of LEED requirements. Furthermore, we researched and discussed different levels of accuracy of cost estimates.

We also examined the environmental policies at other educational institutions that compete with WPI to determine the overall feasibility and benefits of certifying WPI's buildings. We specifically chose to study schools that compete with WPI to determine if construction of LEED certified buildings make WPI more marketable to prospective students. This section provides background information on LEED New Construction Standards, the heat island effect, solar reflectance index, examples of LEED certified projects that meet roof Heat Island Effect criteria, information on environmental sustainability policies at other universities, and a discussion of different types of cost estimates.

2.1 LEED

The LEED certification program was developed by the U.S. Green Building Council (USGBC), a non-profit organization. It was intended to raise awareness of issues related to green construction and to create a standard measurement for "green buildings" in order to increase competition for green construction within the industry (U.S. Green Building Council). Ultimately, the Council hopes that sustainable practices will become common practice and a certification program will no longer be necessary to motivate green building.

Building to LEED standards has many advantages. It reduces the impact a building has on human and environmental health by focusing on five major areas of sustainability: water conservation, efficient usage of energy, site development, material selection, and quality of the indoor environment. Building to LEED standards can also offer direct benefits to the building owner and occupants.

According to the USGBC, green building techniques can reduce energy usage and operating costs by improving the performance of a building. "Studies show that the energy-efficient electrical and HVAC systems in green buildings produce a direct 20-year present value energy savings to the facility of approximately $6.00 per square foot to $14.00 per square foot" (RSMeans, "Green" 231). LEED certified buildings also improve the asset value of the building and promote the owners dedication to sustainability and social responsibility. Green building techniques can improve occupant productivity and reduce absenteeism. Studies published in RSMeans Green Building: Project Planning and Cost Estimating have shown that the improvement of indoor air quality and the use of more light contribute to students progressing 20% faster on math tests and 26% faster on reading tests. Other studies show that green buildings contribute to higher employee retention rates.

Obtaining LEED certification can also help the builder to qualify for tax breaks and other benefits in many cities (U.S. Green Building Council). For example, the development of Gateway Park received a $2.5 million grant from the U.S. Economic Development Administration, but could have qualified for additional forms of government funding had the Bioengineering Center been a LEED certified building. In the past, funding has been provided to other LEED certified projects from sources such as the Massachusetts Renewable Energy Trust, Massachusetts Technology Collaborative, and the utility NStar.

A project achieves certification through a process that includes submitting project photos, typical floor plans, project descriptions and plans outlining how the project will meet the indicated criteria to the USGBC (U.S. Green Building Council). A new construction project is evaluated through six major sections: Sustainable Sites, Water Efficiency, Energy and Atmosphere, Materials and Resources, Indoor Environmental Quality, Innovation and Design Process. Each section has a number of specified items or tasks necessary to receive points and some have prerequisite items that must be completed, but do not offer points toward certification (see Appendix W for a project checklist). There are four different levels of certification: certified, silver, gold, and platinum (U.S. Green Building Council, “New Construction”). Table 1 shows the points required for each level of certification.

Table 1: LEED New Construction Certification Levels

Level	Points Required
Certified	26-32
Silver	33-38
Gold	39-51
Platinum	52-69

Our project focuses on the Heat Island Effect criteria for roof design outlined in the Sustainable Sites and the Materials and Resources categories because these categories are well suited to being studied through a cost analysis. Consideration of other areas of LEED criteria are less relevant in the context of this project because our intent is to study project management and structural design while the other LEED categories deal primarily with building performance. We focused on the Materials and Resources category because this area provides an opportunity for a direct cost comparison of conventional building materials and materials that meet LEED standards. Additionally, we redesigned the roof according to the Heat Island Effect criteria because this approach does not alter the way the building meets the owner's needs and provides a task for a structural design that is achievable within our time constraints. The following section discusses what a heat island is and how its effects can be reduced.

2.2 Heat Island Effect

Heat Islands are urban areas that have higher air and surface temperatures than nearby rural areas (U.S. Environmental Protection Agency). Often, the temperature differences between cities and suburbs can be as large as ten degrees Fahrenheit. The largest urban-rural temperature differences normally occur three to five hours after sunset. This delay occurs because cities retain heat that is stored in roads and buildings and therefore cool off slower than rural areas.

Heat Islands are formed when natural land cover is replaced with pavement and buildings (U.S. Environmental Protection Agency). Tall buildings and narrow streets especially reduce the air flow and heat the air trapped between them. The removal of trees and other vegetation minimizes their natural cooling processes such as shade and evaporating water from leaves and soil. The heat island effect is further exacerbated by waste heat from vehicles, factories and air conditioners.

Reducing the heat island effect can decrease the community's electricity usage. For example, research performed by the U.S. Environmental Protection Agency shows that "In U.S. cities with populations over 100,000 peak utility loads increase 1.5 – 2.0% for every 1 degree Fahrenheit increase in summertime temperature" and over the last several decades, "3 to 8% of community-wide demand for electricity is used to compensate for the heat island effect." Worcester, Massachusetts, the location of WPI's Life Sciences and Bioengineering facility, has a population of 176,000 people (City of Worcester). If more buildings in Worcester were built with roofs that meet LEED Heat Island Effect criteria, the demand for electricity would be reduced.

Cities like Worcester can reduce the heat island effect by installing cooling roofs, cooling pavements, and planting trees and other vegetation. The focus of this project was to design a cool roof to demonstrate how the WPI Life Sciences and Bioengineering center could have helped reduce the Heat Island Effect. Cool roofs reduce building heat-gain and save on air conditioning usage, which reduces overall energy usage, greenhouse gas emissions and air pollution (U.S. Environmental Protection Agency).

Most cool roofs have a smooth, white surface that reflects solar radiation reducing air conditioning usage and the amount of heat transferred into in the building. Cool roof materials have a high solar reflectance and a high thermal emittance. According to the U.S. Environmental Protection Agency, "Solar reflectance is the percentage of solar energy that is reflected by a surface. Thermal emittance is defined as the percentage of energy a material can radiate away after it is absorbed."

Thus, solar reflectance and thermal emittance are important factors that affect surface temperatures and contribute to the heat island effect. When a surface has a low solar reflectance it absorbs a high fraction of solar energy, some of which is conducted into the building and the ground, and some of which is transferred into the air through convection causing temperature rises (ASTM 2).

By measuring the solar reflectance of a given roof, it is possible to calculate the Solar Reflectance Index (SRI), which allows for a direct comparison of the temperature of different roof surfaces under the sun. All SRI measurements are taken with respect to standard black roofing with an SRI of 0 and standard white roofing scaled at an SRI of 100. Using this scheme all values for SRI are interpolated to fall somewhere between 0 and 100 (ASTM 1). Computation of the SRI first begins with a calculation of the steady-state surface temperature for a surface exposed to the sun when the conduction into the material is zero. Using that information and the steady-state temperature of black and white surfaces under standard solar and ambient conditions, the SRI can be calculated (ASTM 2).

According to LEED standards, a minimum SRI of 78 is acceptable for low-sloped roofs, less than or equal to 2:12. Roofs with steeper slopes, greater than 2:12, must have a minimum SRI of 29. The two different requirements come from political issues rather than scientific ones. According to Andre Desjarlais of Oak Ridge National Laboratories, "When the rules were initially proposed, the levels were set so that there were some products in existence that met the requirements. Steep slope products tend to be much darker in color and therefore of much lower reflectance. The level was set so that some steep slope products could meet the requirement." The higher the SRI, the less contribution a roof has to the heat island effect (U.S. Green Building Council, "New Construction" 23).

2.3 Heat Island Effect Examples

In order to further understand methods of heat island effect reduction, we reviewed case studies from LEED-certified projects in California, Washington, and Georgia. The Robert Redford Building, which was a gut renovation in downtown Santa Monica, CA and completed in November of 2003, has several features that conserve energy and include the use of photovoltaic energy and wind power. However, one of the most interesting aspects of the building exterior is the roof. The roof is multi-level, with multiple atria, and uses the building's own rain and gray water treatment system to water these plants as well as to flush toilets. Furthermore, the roof contains monitors that diffuse sunlight and fresh air throughout the building (U.S. Green Building Council, "Robert Redford").

Another LEED project that features a roof that meets Heat Island Effect criteria is the construction of the 14-story Seattle Justice Center. Completed in October of 2002, this facility boasts naturally vented curtain walls that consist of two distinct layers separated by a thirty-inch air space, designed to help minimize heat gain. In addition, this building's "green roof" features low-maintenance plants, making an insulating layer of soil a natural feature on this roof that also "removes solar heat gain through photosynthesis" (U.S. Green Building Council, "Seattle").

Figure 1: Georgia Institute of Technology Management Building, photograph, U.S. Green Building Council, 2 Feb. 2007

In August of 2003, Georgia Institute of Technology completed their new $40 million Management Building that is very similar to WPI's Life Sciences building. This 248,000 square foot facility includes an auditorium, classrooms and retail spaces. While the Management Building incorporates several sustainable features such as water-saving devices and recycled materials, it also helps reduce the heat island effect by the simple use of white heat-reflecting material on the roof (U.S. Green Building Council, "Management Building").

The U.S. EPA New England Regional Laboratory, completed in September of 2001, is a $22 million, 70,400 square foot facility located in Chelmsford, MA. To meet LEED criteria in areas such as Land Use and Materials and Resources, the Laboratory includes features such as

Figure 2: U.S. Environmental Protection Agency New England Regional Laboratory, photograph, U.S. Green Building Council, 2 Feb. 2007

shower facilities and bicycle storage for bicycle commuters, access to public transportation, the use of steel with the highest possible content of recycled material, and a waste management plan provided by the contractor (U.S. Green Building Council, “Regional Laboratory”). The success of this facility in achieving LEED Gold certification demonstrates that even laboratory facilities, which are traditionally thought of as harmful to the environment, can take steps to reduce their environmental impact.

The examples above have shown that meeting the Heat Island Effect criteria is one way to reduce the environmental impact of buildings and can be used on a variety of building types. Recently, many college campuses across New England recognized the benefits of sustainable practices, took steps towards implementing these practices, and are now experiencing positive results in terms of energy savings, and occupant morale and productivity.

2.4 Environmental Policies on College Campuses

Effective environmental policy goes beyond highly reflective roofs and the use of recycled materials for construction. This section discusses research performed on the “green” policies of universities in the Northeast that are of a similar caliber and reputation, and draw from the same pool of applicants as WPI. These universities not only see the environmental impact and cost savings of green engineering, but also an impact on the university’s prestige, which aid in the institutions ability to attract potential students (Nitsch). Therefore, the purpose of this section is to gain some awareness of how other universities are approaching green building and to assist WPI in benchmarking its own status in this area.

2.4.1 University of Connecticut

The University of Connecticut (UConn) developed an Environmental Policy Statement in 2004 (revised May, 2006) that outlines the University's approach to handling their impact on the environment. The policy is broken down into six categories: performance, responsible management and growth, outreach, academics, conservation, and teamwork (University of Connecticut). In order to give focused attention to each of these areas, there are three subcommittees that work to develop and evaluate the University's performance. The Land Use and Sustainable Development subcommittee works with the University's construction program to help facilitate green building practices, and also works for open space conservation, natural resource protection, and habitat restoration. The Compliance and Best Practices subcommittee focuses on waste management procedures, conserving resources, and the minimization of air and water quality impacts. The third committee, for Environmental Outreach, works to increase awareness and personal responsibility, enhance environmental literacy, and to improve the university's reputation and community relations.

As an example of the tasks performed by each of these subcommittees, consider the Compliance and Best Practices committee. In the 2004-2005 school year, the committee had four workgroups: Greenhouse Gas Emissions, Fleet Fuel Efficiency, Biodiesel Initiative and Water Conservation (University of Connecticut). Each workgroup had a set of goals, tracked their progress, and planned for the future. One particular achievement made by the Water Conservation workgroup was the replacement of washing machines on campus with high efficiency washing machines, which will result in an estimated 2.6 million gallon reduction in water usage per year.

In addition to the Environmental Policy Statement, UConn has a document called "Sustainable Design Guidelines," which uses LEED criteria as a sustainability benchmark, but also "tailor[s] LEED to respond to regional issues and campus culture, and also integrate[s] it with its existing building delivery process" (University of Connecticut). The Burton Family Football Complex and the Mark R. Shenkman Training Center are examples of the success of UConn's sustainable design guidelines. This athletic facility is the first LEED registered complex in the NCAA.

2.4.2 Massachusetts Institute of Technology

The environmental policy at the Massachusetts Institute of Technology (MIT), also know as "MIT's Commitment," is active at their highest levels of administration and is evident throughout their community. This policy is outlined by three objectives, the first of which is "honoring our legacy of leadership in science, technology, and innovative problem solving" (Massachusetts Institute of Technology). The other main objectives are promoting research and activities that support MIT's environmental standards that embody stewardship and extend beyond local and federal regulations, and protecting the environment and welfare of the community.

Three groups were formed in order to work toward these objectives: the Council on the Environment, the Environmental Programs Office, and the Environmental Health and Safety Council (Massachusetts Institute of Technology). The Council on the Environment develops environmental research and academic programs. Environmental policymaking, coordination of MIT-wide environmental initiatives, and the overall environmental, health, and safety management at MIT are the main tasks of the Environmental Programs Office. The application of MIT's environmental goals of research and administrative operations is the responsibility of the Environmental Health and Safety Council.

In working toward meeting their environmental objectives, MIT has developed a set of measurable goals to facilitate the evaluation of their progress (Massachusetts Institute of Technology). Some of their many goals are as follows: reduce per capita energy consumption, improve indoor and urban environment, and educate students in sustainable concepts. MIT has already taken significant steps toward meeting their environmental objectives. For example, all major renovations and new construction will be designed to exceed LEED Silver standards.

Other achievements that benchmark the progress of MIT's environmental policy fall into the categories of recycling and resource conservation. MIT has increased its overall monthly recycling rates from 10.5% to over 35%, as a percentage of total tonnage of material recycled compared to total amount discarded. The Institute also practices food composting through collecting food waste from kitchens and turning it into compost used at a local nursery. Scraps from food preparation are handled separately and collected by a designated organics hauler. These practices save money on trash collection and reduce rat problems near trash areas since food waste is picked up daily.

Resource conservation is another area where MIT has taken drastic measures to improve. In one building on campus, a water reclamation and reuse system was put in place. This system cost $140,000 to install, but saves $160,000 annually, and has reduced annual water consumption in that building from 27.6 million to 3.6 million gallons (Massachusetts Institute of Technology).

2.4.3 Carnegie Mellon

Carnegie Mellon University has an extensive environmental sustainability plan involving the entire campus community (Carnegie Mellon University). The University began their environmental sustainability efforts in 1990 with the establishment of a formal recycling policy and the hiring of a Recycling and Waste Coordinator. In 1998, the University created the Green Practice Committee, comprised of faculty, staff and students, to address environmental issues such as “recycling, purchasing, energy use, dining, buildings and construction, transportation and communications and outreach” (Carnegie Mellon University). This committee has started outreach programs and developed University policies to “improve environmental quality, decrease waste, and conserve natural resources and energy … [to establish] Carnegie Mellon as a practical model for other universities and companies” (Carnegie Mellon University).

Carnegie Mellon now has policies in place to pursue LEED Silver Certification for all new buildings on campus, to purchase alternative fuel vehicles for campus use, to buy only recycled printer and copier paper, and to buy a portion of electricity from wind power. As a result of these policies, the University now has three natural gas cars, two for Facilities Management and one for Campus Security, and one electric vehicle. It is also the largest buyer of wind power in the United States. Within ten years, Carnegie Mellon had increased its percentage of recycled waste from 5% to 13% and they also have two LEED certified buildings and many roofs of existing buildings are being retrofitted to be “green” roofs.

2.4.4 Worcester Polytechnic Institute

Currently, WPI does not have a formal "environmental policy." Though the University has taken some steps to reduce its environmental impact by working toward LEED certification for the construction of the Bartlett Center (2005), WPI is still a long way from reaching the level of environmental awareness and active policy production that comparable universities have attained.

The next portion of this report uses the information outlined in this chapter as the foundation for determining the feasibility of building the WPI Bioengineering Center to LEED Materials and Resources standards and designing an alternative roof to meet LEED Heat Island Effect criteria

2.5 Cost Estimate Levels of Accuracy

In order to provide a general outline for what a cost estimate should look like, we consulted the Means Estimating Handbook. This section will be used to provide a baseline for comparison with the method we used for the cost analysis of this project. In general, there are four different levels of cost estimates that can be performed: Order of Magnitude, Square Foot, Assemblies, and Unit Price. Each type of estimate requires a different amount of time and information, and achieves a different level of accuracy. The Means Estimating Handbook describes each of these methods in detail:

> Order of Magnitude Estimate: This type of estimate can be defined as a form of educated guess. It takes only minutes to complete and can be derived from relatively small amounts of information. The accuracy to be expected from this type of estimate is -30% to +50% of the project cost.
>
> Square Foot Estimate: Used when only the proposed size and use of the building is known, this type of estimate can achieve accuracy ranging from -20% to +30% of the actual project cost. In a typical Square Foot Cost estimate, costs are broken down into different components and then a cost per square foot is determined.
>
> Assemblies Estimate: An Assemblies Estimate is typically used as a budgeting tool in the early stages of project planning. It organizes the building into a few major components and prices the systems (assemblies) within those components. An accuracy of -10% to +20% is typically achieved through this type of estimate.

Unit Price Estimate: The most detailed type of estimate, a Unit Price Estimate requires full working plans and specifications and is typically used for bidding purposes. Accuracy within -5% to +10% of actual project cost is typical.

No matter which type of estimate is required, there are some general guidelines that should be adhered to. The Means Estimating Handbook recommends practices such as showing the dimensions of each item, checking the plans frequently and carefully for changes in scale, using decimals places instead of fractions, and marking items on the plan sets as they are measured or “taken off”.

The quantity takeoff itself has two processes: quantifying and tabulating. Quantifying is the process of counting all materials. Once all materials have been quantified, they are tabulated and assigned a cost. Current software, such as Microsoft Excel, allows for the creation of spreadsheets and can facilitate the practice of quantifying and tabulating simultaneously. However, during both parts of the quantity takeoff, consistency is the most important consideration.

Once all materials have been tabulated, the next step is to assign a cost to each item. The four types of project estimates include both direct and indirect costs. Direct costs are linked to the physical construction of the project while indirect costs are incurred during project completion, but are not applicable to any specific task. Examples of indirect costs include overhead, profit, salaries, taxes, equipment and contingencies. The final step in preparing a cost estimate is to create an estimate summary sheet. This sheet typically lists the total from each category of work, shows the addition of indirect costs not already included in the estimate, and presents the total estimated project cost.

The next chapter outlines the methods used to complete this project and uses the information outlined in this chapter as well as additional information obtained from independent research and course work at WPI to describe the steps taken to reach our project goals.

3.0 METHODOLOGY

Through background research, we have verified that constructing a laboratory facility that meets LEED standards is not only obtainable, but also beneficial. In order to determine the feasibility of building the WPI Life Sciences and Bioengineering Center to the LEED Materials and Resources standards and Heat Island Effect criteria we developed five major objectives:

- Identify materials and resources used in the current design of the WPI Life Sciences and Bioengineering Center
- Identify the materials and resources needed to meet LEED specifications
- Conduct a cost comparison and determine availability of materials
- Redesign the roof to meet Heat Island Effect criteria
- Evaluate costs and benefits of meeting the Materials and Resources criteria and the Heat Island Effect criteria

Our methods of achieving these objectives are outlined in the following five sections.

3.1 Identify the Materials and Resources Used in the Current Design of WPI Life Sciences and Bioengineering Center

We began work on our project through research on the history of Gateway Park and its status as a brownfields site. In addition, we visited the site to view the construction activity and gain a comprehensive understanding of the project as a whole. The extensive custom work and the magnitude of this project made it unfeasible for us to identify all of the materials used for the entire building within our time constraints. Therefore, to identify the materials used, we divided the building materials into two parts, separating the interior finishes from the other building components. To identify the resources used, we consulted with Consigli Construction Company.

In order to find the cost of the interior finishes for the entire building, we calculated the cost per square foot of the interior finishes for a small, yet representative portion of the building and multiplied this square footage cost by the area of the whole building, arriving at a total estimated cost for the interior finishes. We used the Plant Systems Lab (Room 4212) as our typical lab space for determining the cost per square foot of the interior finishes because we surmised it to be more expensive than some of the office spaces in the building, but less expensive than some of the other labs that have more equipment. For the materials that we did not classify as interior finishes, such as structural steel members, brick facing and insulation, we performed a quantity takeoff of the entire building and added this unit cost to one calculated for the plant lab. Our estimate did not include HVAC, MEP or smaller building components. For a complete list of the building materials that we estimated, see Tables 4 and 5 in Results section 4.2. We used drawings and specifications provided by Consigli Construction Company to identify the materials included in our cost estimate.

The Materials and Resources category encompasses not only the materials used, but also the amount of waste produced by construction. Correspondence with members of Consigli's construction management team helped determine how they disposed of construction waste and if they recycled any of it. We also maintained our knowledge of the progress of construction of the WPI Life Sciences and Bioengineering Center by attending weekly owner's meetings and compiling meeting minutes (see Appendix AA).

3.2 Identify the Materials and Resources Needed to Meet LEED Specifications

After identifying the materials used in our estimate, we determined if any of those materials already met the LEED Materials and Resources standards and researched materials that could be substituted for any materials that did not already meet LEED standards. More specifically, we looked for materials that satisfy one or more of the following:

- Made from post-consumer and pre-consumer recycled content
- Salvaged, reused or refurbished
- Extracted, processed and manufactured locally
- Rapidly renewable
- Certified wood

3.3 Analysis of Cost and Availability of Materials

We compared the cost of the materials used in the design of Gateway Park to the cost of using alternative materials that meet LEED specifications. In order to accomplish this, we developed a cost per square foot value for the interior finishes in the existing typical lab and applied this unit cost to the entire building to estimate the total cost of interior finishes.

We found the unit prices of all interior finishes in the lab space from 2007 RSMeans reference books and through information from suppliers. We divided the lab into sections in order to better organize the takeoff process. To calculate the cost per square foot of the laboratory interiors, we divided the total cost of the interior finishes in the lab by the square footage of the lab.

Once the cost per square foot of the interior finishes had been calculated, we combined it with the total cost of the quantity takeoff of the materials we identified in the rest of the building to find an overall cost of the materials we quantified in the existing building. Finally, we substituted materials that meet LEED standards into the design to get a new cost of those materials. We compared the two estimates to determine the overall cost difference between the materials actually used in construction and the materials that could have been substituted to meet LEED standards. This analysis also verified which materials had the greatest impact on overall cost.

3.4 Roof Redesign to Meet Heat Island Effect

The second major task in our project was to redesign the roof to meet the LEED Heat Island Effect specifications. In order to complete this, we performed a structural analysis of the existing roof which helped us to identify the sources and magnitudes of the applied loads for use in our alternative roof design. Furthermore, we investigated the capacity of the existing members to give us practice in applying the structural engineering techniques necessary for the design and analysis of our new roof. In order to determine the applied loads, we used information obtained from the Massachusetts State Building Code to determine the design live load and found that for this building, the snow load governed. Information from the specifications, drawings, and manufacturers was used to determine dead loads on the roof, including the loads produced by the mechanical systems and the roof screen.

Once we had determined the design loading conditions, we used a plastic capacity check to determine if the member sizes were adequate. Note that we performed a calculation to verify that the members had a compact section, could reach plastic capacity, and found that the majority of the members did. For those members with a non-compact section, we interpolated between the individual properties of the member and the member's plastic capacity to determine the member's actual moment capacity.

In the case of the girders, the methods used to verify member sizes differed from the typical calculations for beams in various ways. For example, girders have fixed-end connections while we assumed that the beams have pinned-end connections. Girders also support the weight of beams, so the additional weight of the adjacent members had to be taken in to account. In order to facilitate the girder calculations, we divided the girders into three categories: Type I, Type II, and Type III (see Figures 3, 4 and 5). Type I girders are those that support adjacent beams throughout their entire tributary area, and includes girders along the edge of the roof that only have beams on one side as well as interior girders that support beams on both sides. Type II girders support beams over half of their tributary area, and Type III girders support other girders.

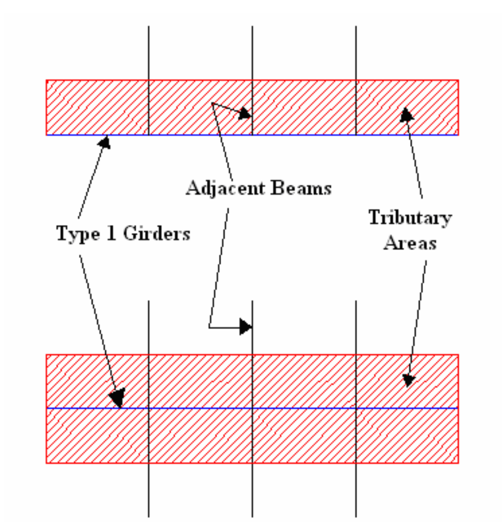

Figure 3: Type I Girders

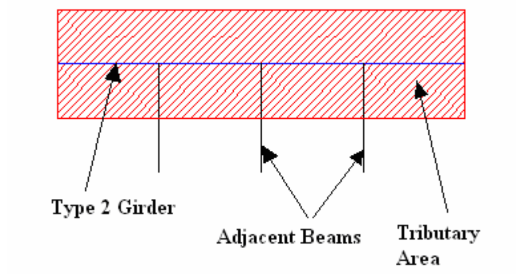

Figure 4: Type II Girder

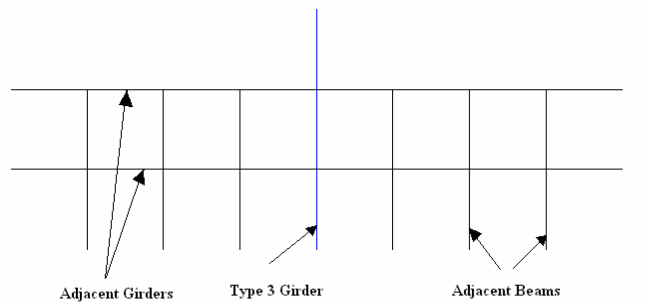

Figure 5: Type III Girder

While each type of girder required a different calculation to determine design moments, we made some assumptions that are common to each type. The adjacent beams were always treated as uniform loads distributed over the length of the girder and the average nominal weight of those beams was used in calculating that load. In order to compute the effective distributed load of adjacent beams along a girder, we divided the average nominal weight of the beams by their individual tributary widths and multiplied that value by the tributary width of the girder in order to find the effective linearly distributed load along the girder itself. Using these values for distributed loads and methods outlined by the AISC, we were able to determine if the girders possessed adequate shear and moment capacity to support the weight of the roof. See Appendices E through K for a detailed explanation of these calculations.

After analyzing the existing roof, we evaluated possible ways to meet the LEED Heat Island Effect criteria (see Appendix X for LEED Heat Island Effect – Roof Criteria). The biggest obstacle in the alternate roof design was providing adequate clearance for the mechanical units. The mechanical units closest to the edge of the roof stand approximately twelve feet above the flat surface. Overall, the tallest mechanical unit is the lab exhaust system that stands eighteen feet above the flat surface of the roof, but we used the assumption that the exhaust manifolds would be accommodated by penetration through the roof. With this is mind, we looked at two schemes (see Figures 6 and 7).

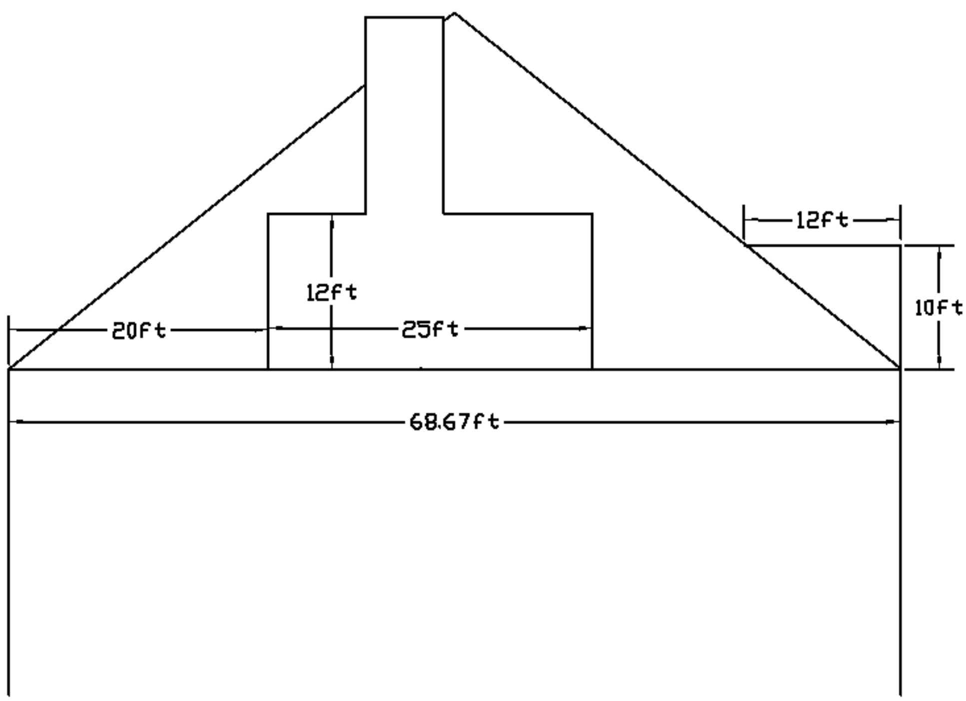

Figure 6: Scheme 1, Steep-Slope

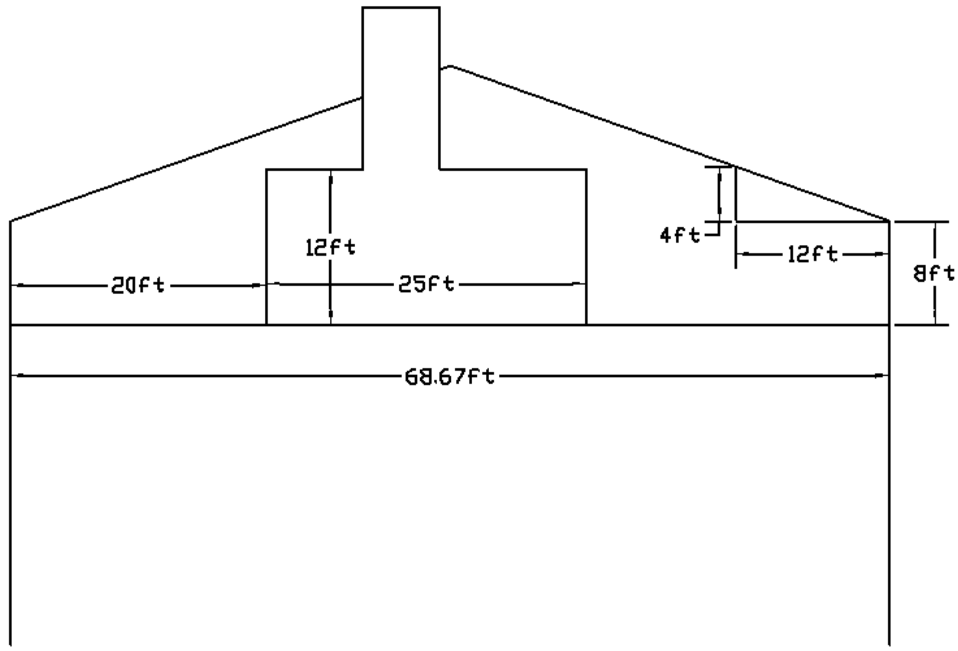

Figure 7: Scheme 2, Low-Slope

The first scheme was to extend a steep-sloped roof on the existing building. The second scheme was to extend the vertical walls before building a sloped roof. Our first consideration in comparing the alternatives was the additional height each would add to the building. We verified the zoning requirements and found that there were no direct building height limitations for the zone in which Gateway Park is located. However, building height is governed by a lot-to-floor area ratio of one to six, which means that the total floor area of the building cannot be more than six times the size of the lot. We determined that neither scheme would exceed this ratio.

Another major factor in the comparison of roof designs was cost of construction. We estimated the amount of typical materials each roof would require. We considered brick, roofing material and steel to develop a proportional cost for each alternative. At this stage we assumed that the roofing material was the same for each alternative since both slopes fall under the same minimum SRI requirement. When estimating steel quantities, we made several assumptions. We assumed that all steel members would be the same size within each alternative, and that each member in each alternative had the same tributary width and dead load for the roofing materials. Using AISC methods we sized a typical member for the two roof schemes and used unit price data from RSMeans Building Cost Information 2007 to determine their relative prices. We estimated that the steep-sloped roof cost $65,500 and the low-sloped roof cost $63,500 (see Appendix R for a breakdown of these costs). However, the low-sloped roof requires more than twice as much brick work, and because we neglected to include mortar or labor costs in our estimate, we predict that the steep-sloped roof would actually cost less if a complete estimate were completed. Also, the steep-sloped roof would be more attractive in that it does not extend an unaesthetic, windowless brick wall an additional eight feet. As a result of this analysis and comparison, we decided that a steep-sloped roof would be the best design.

Once we decided on the general design of the roof, our first step was to research materials that meet the required Solar Reflectance Index. We selected galvanized steel with an SRI of forty-six (Lawrence Berkeley National Laboratory). Structural engineering techniques were used to develop a roof design that supports the alternative roofing material with an adequate slope to meet the Heat Island Effect criteria as determined by LEED standards. In addition to supporting the dead and live loads as required by the Massachusetts State Building Code, the alternative roof design also accommodates the mechanical equipment that is currently located on the roof. Refer to

Table 2 to find which appendices contain further information about the current roof, the mechanical units and the new roof design.

Table 2: Appendices Containing Roof Design Information

Roof Plan	Appendix B
Summary of all Member Capacity Checks	Appendix C
Typical Beam Calculation	Appendix D
Typical Type I Girder Calculation	Appendix F
Typical Type II Girder Calculation	Appendix H
Typical Type III Girder Calculation	Appendix J
Type III Adjacent Member Dead Load Calculation	Appendix K
Moment Capacity for members with non-compact sections	Appendix L
Mechanical System/ Roof Screen Distributed Load	Appendix N

Once the new roof load had been determined, the actual design of the roof began to take shape. Within the steep-sloped roof scheme, we developed structural designs for two separate options. In the first option, beams would be placed parallel to each other in a basic rafter layout, perpendicular to the roof ridge much like the roof structure in a traditional wood framed building. In the second option, girders would be laid out like the beams in option one except that they would be connected by a series of open-web joists. The joists would run perpendicular to the girders and parallel to the length of the roof and the sill beams. Sill beams support the entire weight of the roof and transfer the load to the columns. See Figures 8 and 9 for sketches of the two framing options.

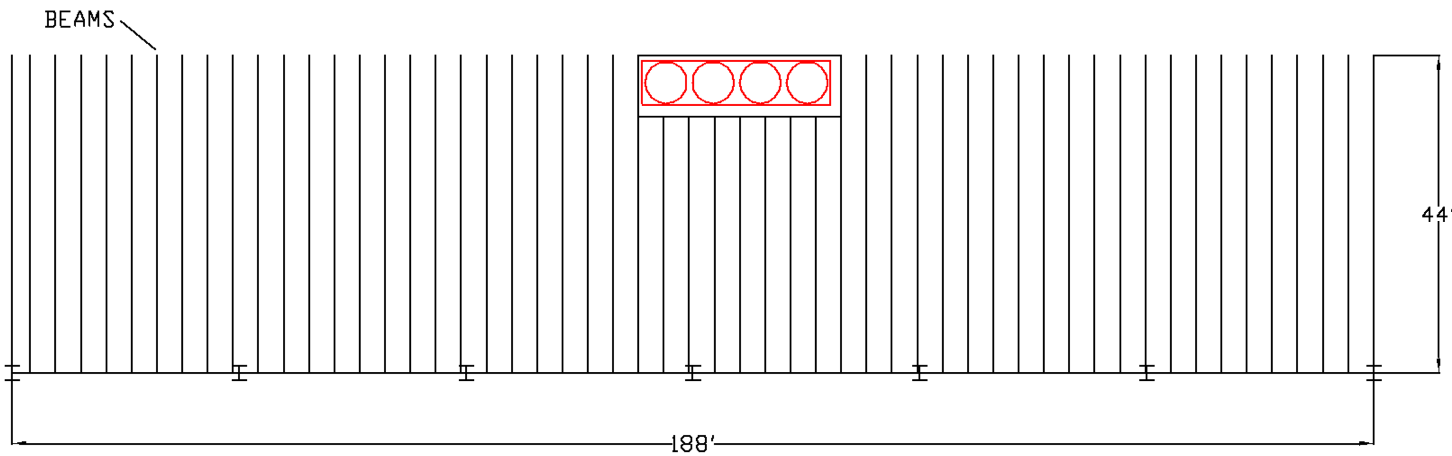

Figure 8: Roof Design Option 1

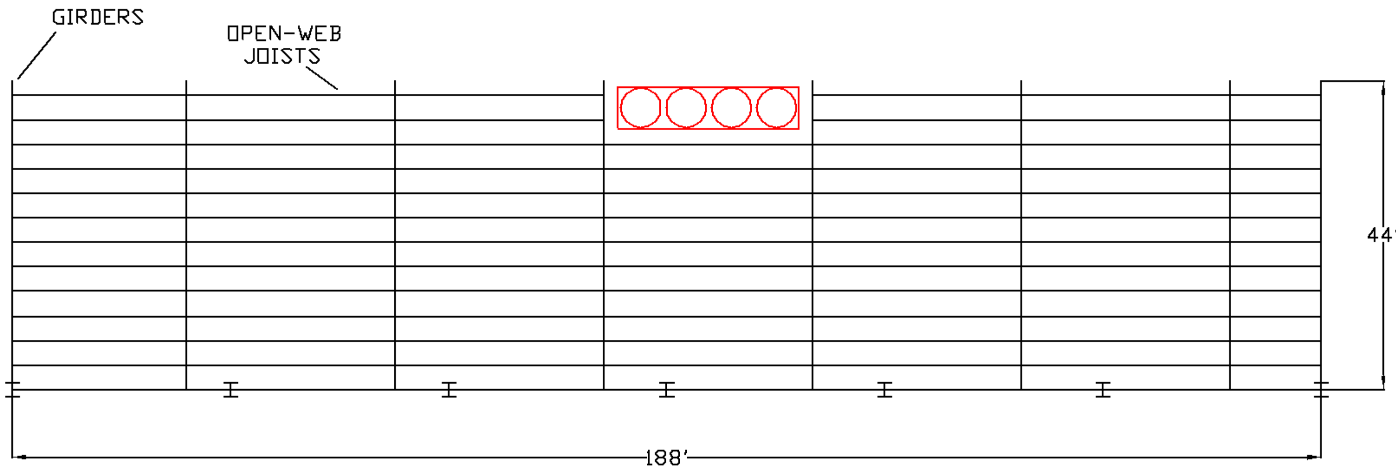

Figure 9: Roof Design Option 2

Certain assumptions had to be made for each of these two options in order to develop a design that was both adequate and cost effective. Using the AISC Steel Manual and the Massachusetts State Building Code requirements for dead, live, and wind loads and the weight of the metal roofing material with the required SRI, we determined the design loads and in turn the appropriate beam sizes necessary to develop an adequate design scheme.

In the case of the first option, design was fairly straight foreword in the sense that the only major design variable became the spacing of the beams. Therefore, using the LRFD method on a sample of different beam spacing options, we were able to calculate the minimum required cross-sectional Z_x value and, in turn, the beam size necessary to withstand the given roof loads.

We then compared the cost of each of these options of to decide on the most economical roof choice. Special consideration also had to be made for the mechanical equipment exhaust vents located near the center of the roof because they extended beyond the roof height at that point. In order to accommodate this twenty-six foot wide unit, we were required to define a beam spacing that provided enough clearance on either side of the unit, and also add a small girder as a header to support the beams that were prevented from extending all the way to the roof peak. Later on we determined that because of the specific steel roofing material that we had chosen, the maximum spacing between beams was limited to 3.5 feet, which eliminated a majority of the possible beam arrangements and increased the minimum cost of constructing this option.

As an alternative to this design, we decided to use an open-web joist and girder combination. We decided to use open-web joists to span between the girders because of the maximum unsupported span of 3.5 feet dictated by the steel roof stiffness. We realized that W-sections were too bulky, over-designed and expensive for the comparatively short 3.5 foot tributary widths they had to support.

The use of open-web joists also made the methods behind our design analysis simpler because, given the maximum tributary width, even the smallest available joist type was capable of easily sustaining the given loading conditions. Therefore, joist size became dependent only on the length dictated by the tributary width of the girders. By fixing the joist tributary widths at their maximum of 3.5 feet, we effectively eliminated joist spacing as a design variable allowing the design to be dictated by the desired spacing of the girders. Using the LRFD method on a sample of different girder spacing options, we were able to calculate the minimum required Z_x for girder design.

Like option one, option two also dealt with the issue of the protruding twenty-six foot wide mechanical exhaust unit. Given the width of the unit we needed to develop a girder spacing that exceeded twenty-six feet. Without consideration of the unit, the unimpeded roofing option with the lowest cost consisted of a twenty-six foot girder spacing. For design ease, we decided to try the next lowest cost option, twenty-eight foot spacing, and simply remove the joists in the area where we needed to fit the mechanical unit. However, given the location of the exhaust unit, two extra girders would need to be installed, effectively making it more expensive than the thirty foot spacing option. As a result, we decided that the option with thirty foot girder spacing would be the most cost effective choice to accommodate the mechanical exhaust unit.

This chapter discussed the steps we followed in order to assess the feasibility of building the WPI Life Sciences and Bioengineering Center to meet the criteria of the

LEED Materials and Resources Category and the steps taken to design an alternative roof that meets the Heat Island Effect criteria. The next chapter discusses the results of our cost analysis and roof design.

4.0 RESULTS

Through setting clear objectives and outlining the procedure required to achieve them, we were able to analyze the existing roof, design an alternative roof to meet the LEED Heat Island Effect criteria, determine the cost of the materials used in construction, and the cost of materials that meet the LEED Materials and Resources criteria. This section describes the results achieved through our roof analysis and design, and cost comparisons.

4.1 Roof Design

Using the LRFD methods outlined by AISC for steel roof design, we have achieved two separate sets of results. These results reflect calculations and design techniques outlined in our methodology and are displayed and discussed below in sequential order beginning with the analysis of the existing roof design and concluding with the results for the alternative roof design.

4.1.1 Existing Roof Design

In order to gain a better understanding of the design process, we performed a structural analysis of the existing roof, which helped us to identify the sources and magnitudes of the applied loads for use in our alternative roof design. Furthermore, by investigating the capacity of the existing members, we gained experience in applying the structural engineering techniques necessary for the design and analysis of our new roof. As we had expected, all the members in the existing roof were designed adequately to withstand their given loads. More importantly, we sought to determine the degree of adequacy of the roof design. In the process, we noticed that there were certain trends in the design that warranted further explanation. For example, we found that in general, the actual moment force exerted on the beams divided by the beam capacity was slightly greater than one. See Appendix C for a detailed list of the actual moment values and their respective design moment capacities.

As Figure 10 and Figure 11 below illustrate, a majority of the design moment to actual moment ratios reside slightly above one, indicating that the members were designed adequately to resist their loads without being over designed. However, in some cases there are beams and girders with capacities that are significantly greater than their actual loads. Manufacturability is an important reason why this happens. In an effort to maintain consistency in member size, it is not uncommon for engineers to design a member for the highest possible load, and then replicate the design through other members with smaller loads in order to create uniformity. Thus, when it comes to purchasing, fewer sizes of members can be purchased in larger quantities. Though some of the members may be over designed, it is easier to manufacture and erect more of the same size pieces, creating a lower overall cost for the material.

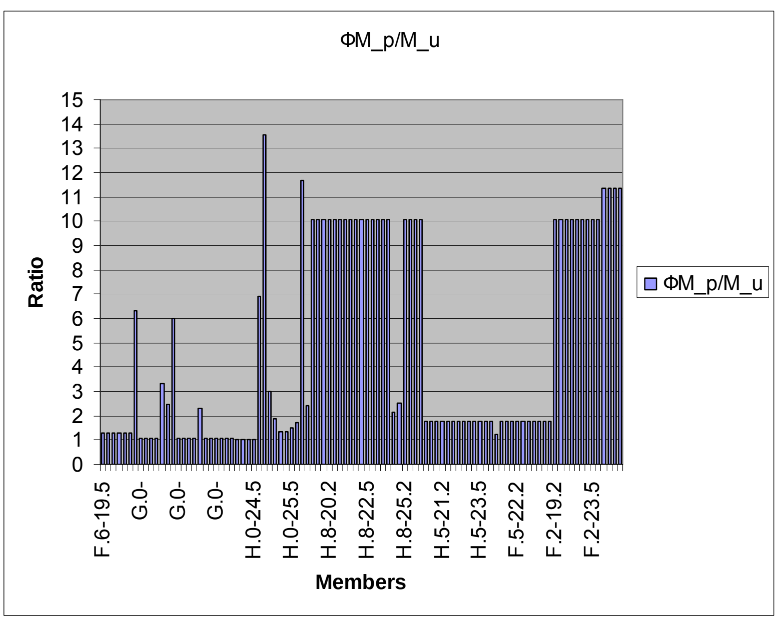

Figure 10: Design Moment vs. Actual Moment Ratio for Beams

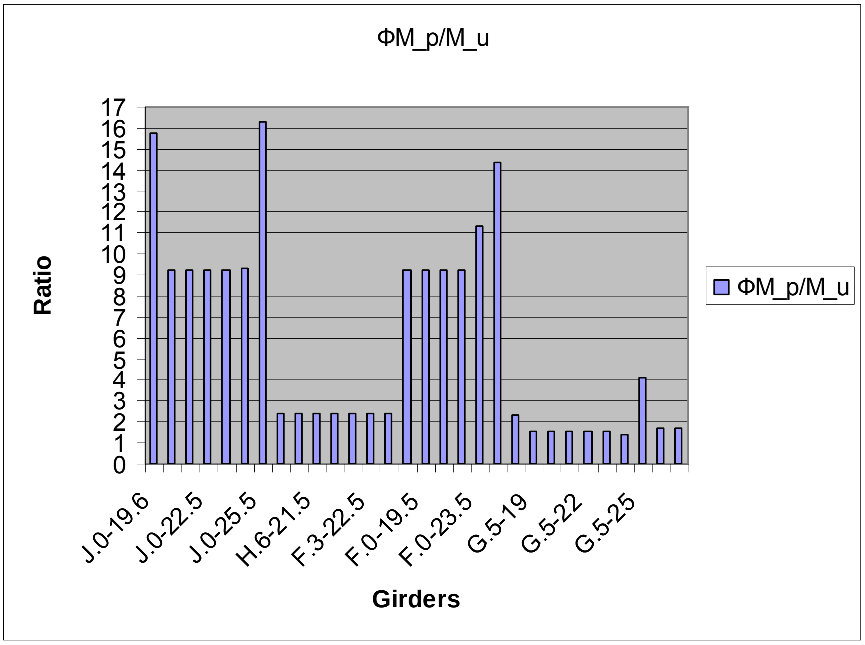

Figure 11: Design Moment vs. Actual Moment Ratio for Type 1 Girders

4.1.2 Alternative Roof Design

Once we had analyzed the existing roof, we developed a new roof design for the existing WPI Life Sciences & Bioengineering Center that met the LEED roof certification requirements for the Heat Island Effect criteria. In order to meet this requirement, the roof must be constructed from a material with a SRI greater than twenty-nine for the selected slope of our roof. After considering several types of materials, we chose to use the Berridge Zee-Lock Standing Seam System because it exceeds the required solar reflectivity and is suitable for use over open purlins (Berridge). Once we decided on this specific product, we developed our roof design accordingly. As discussed in the methodology section, a roof that simply consists of a series of parallel beams acting as rafters does not make sense for the minimal loading condition on a sloped roof. A rafter layout does not make sense because it would be too bulky, over designed, and expensive for the comparatively short open spans. Therefore, we chose the open-web joist and girder combination that incurred the lowest cost but still provided adequate support for the roofing material and sufficient space between girders for the exhaust system to protrude through the roof.

After considering several joist/girder combinations, we selected W21x50 girders spanning perpendicular to the ridge of the roof and spaced every thirty feet. Placed every 3.5 feet and running parallel to the ridge, we chose 16K4 joists spanning the distance between the girders. The roofing material, joists, and girders are supported along either eave by two W21x44 sill beams that span the columns in the framing of the building and transfer the weight of the roofing and framing to the columns. See Figures 12 and 13 for detailed drawings of the alternative roof design.

Aside from beam loading capacity, cost effectiveness also played an important role in the selection of the roof member sizes. Without accounting for the twenty-six foot width of the mechanical equipment exhaust units, the lowest cost alternative consisted of girders spaced at twenty-six feet and joists at 3.5 feet. As described in our methodology, we ran into some difficulty with this design and were forced to select an option that cost slightly more than the unimpeded twenty-six foot design but provided the necessary spacing required to sustain the constraints of the units. Using <u>RSMeans Building Construction Costs 2007</u>, we estimate that the framing and roofing materials for this roof will cost $127,840 and is the most economical solution adequate enough to meet the requirements of mechanical exhaust units and the LEED roof Heat Island Effect criteria.

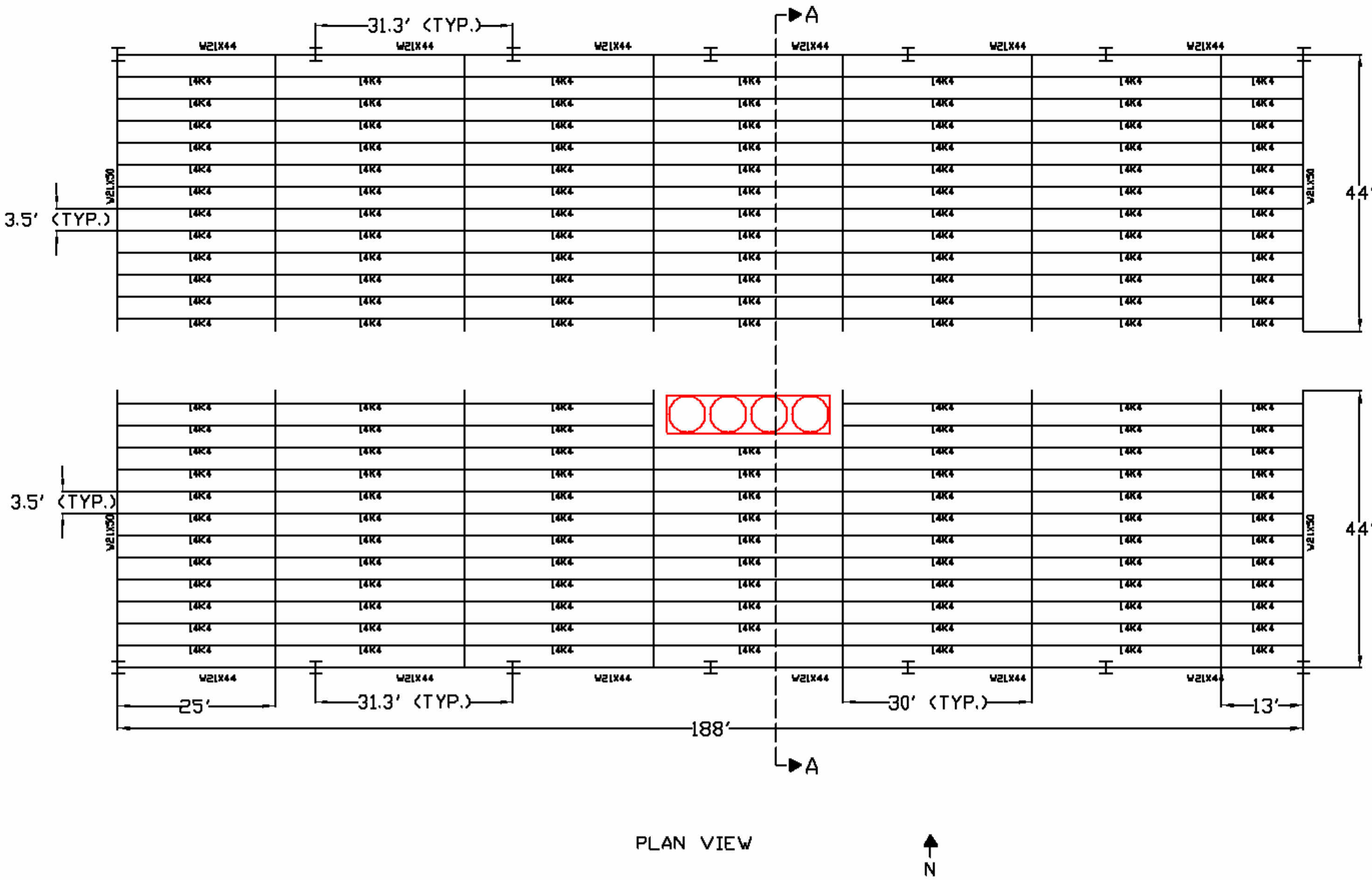

Figure 12: Alternative Roof Plan

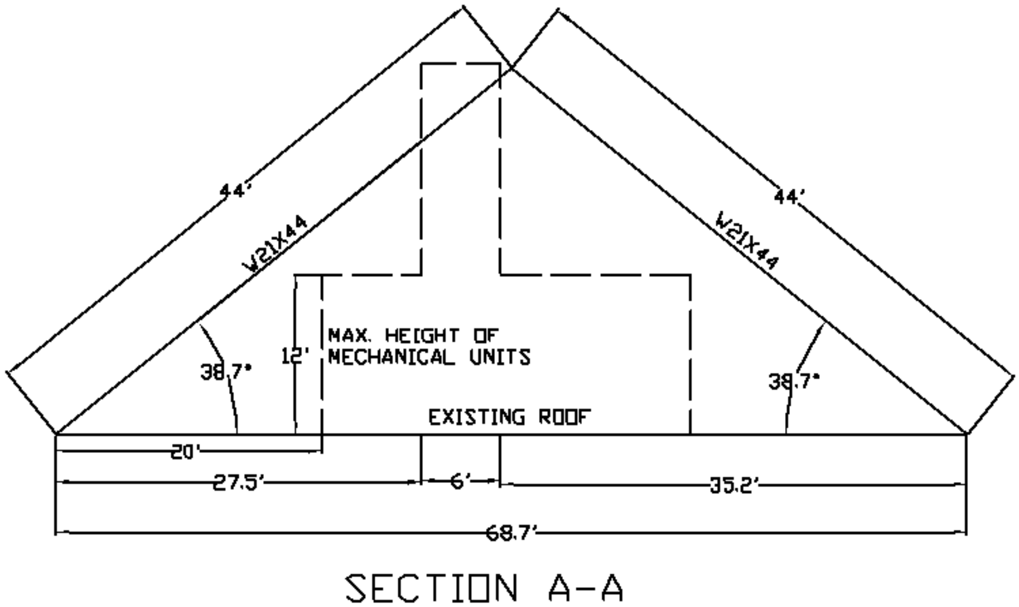

Figure 13: Cross-Section of Alternative Roof Plan

4.2 Cost Analysis

In conjunction with designing a roof to meet LEED Heat Island Effect criteria, we performed a cost comparison between some of the materials used in construction and materials that could have been substituted in to earn the points. Based on the items analyzed in our cost analysis, we have found that it would cost three percent more to build WPI's Life Sciences and Bioengineering Center to the LEED Materials and Resources Category. Table 3 compares the estimated cost of the materials used in construction to the estimated cost of meeting the criteria of the Materials and Resources Category.

Table 3: Total Cost Comparison

Cost of Identified Materials	$3,097,118.71
Cost of Identified Materials with LEED substitutions	$3,196,184.25
Price Difference	$99,065.54
Percent Difference	3%

The costs above pertain only to major materials used. The cost of labor, mechanical, electrical, and plumbing work, and minor items such as door hardware, were not included. For a complete list of items included in our estimate and itemized costs, refer to Table 4, 5, and 6.

We used our cost estimate to determine if it was possible for this project to achieve all points available in the LEED New Construction Materials and Resources category and to determine which items had the largest affect on the cost of the project. This section will outline the requirements of each Materials and Resources criteria and identify the items that most influence the cost of the project.

Table 4: Cost Estimate Interior Finishes Summary of Results Part I

Plant System Lab 4212										
Item Description Given in Plans	**L (ft)**	**W (ft)**	**H (ft)**	**Source**	**RSMeans Description**	**RSMeans Code**	**Quantity**	**RSMeans Unit**	**RSMeans Unit Cost**	**Standard Total Cost**
Natural Gas House System	-	-	-		*	-	2	EA	$44.00	$88.00
Lab Vacuum House System	-	-	-		*	-	4	EA	$44.00	$176.00
Vinyl Composition Tile Flooring				2	Vinyl Composition Tile 12"x12", 3/32" thick, solid	09 65 19.10 7300	434	SF	$2.00	$868.00
Biology Island Bench										
Drawer Units 1'9" wide	1.8	2.0	2.8	1	Manufactured Wood Casework Kitchen Base cabinets, 4 drawers, 24" wide	12 32 13.10 1060	4	EA	$345.00	$2,415.00
Floor Cabinets	1.8	2.0	2.8	1	Manufactured Wood Casework Kitchen Base cabinets, 1 top drawer. 1 drawer below, 21" wide	12 32 13.10 0860	4	EA	$242.00	$968.00
Countertop	12.0	5.0		1	Laboratory Countertop, Acid proof Maximum	12 36 53.10 0030	60	SF	$37.50	$2,250.00
Shelving unit: 1 1/4" particle board with maple vaneer w/ 1/4" solid maple edge banding on all edges	3.8	1.0	0.1	1	Manufactured Wood Casework Frames, Book cases, one bay, 7' high, 36" wide	12 32 13.15 0300	18	LF	$80.00	$1,440.00
Prefab Electrical Raceway	12.0	0.2	0.1	1	Plugmold wired sections, #2000	26 27 23.40 4100	12	LF	$52.50	$630.00
Light Fixture under shelf	12.0	0.4	0.1	1	Interior Light Figures - Strip fixtures, 4' long, two 60 watt, HO	26 51 13.50 2800	6	EA	$86.00	$516.00
Biology Island Bench End Unit										
Shelving unit:1" particle board with maple vaneer w/ 3/8" solid maple edge banding on all edges	2.5	1.0	3.0	1	Manufactured Wood Casework Frames, Book cases, one bay, 7' high, 36" wide	12 32 13.15 0300	2	EA	$80.00	$160.00
Adjustable book shelf unit: wood vaneered 1" mdf with 3/8" hardwood edge band	2.5	1.0	3.0	1	Manufactured Wood Casework Frames, Book cases, one bay, 7' high, 36" wide	12 32 13.15 0300	2	EA	$80.00	$160.00
Epoxy Resin Countertop	5.0	1.7		1	Laboratory Countertop, Acid proof Maximum	12 36 53.10 0030	9	SF	$37.50	$337.50
Corridor Units										
100 lb. Capacity Wood Shelf	2.0	0.7	2.0		**	-	2	LF	$3.57	$7.14
24"x30" Epoxy Peg Board	2.0		2.5		39 Pegs*	-	1	EA	$255.00	$255.00
Paper Towel Holder	-	-	-	1	Towel Dispenser, Stainless steel, surface mounted	10 28 13.13 6700	1	EA	$39.00	$39.00
Soap Dispenser	-	-	-	1	Soap Dispenser, Chrome, surface mounted, liquid	11 28 13.13 4600	1	EA	$51.50	$51.50
Eye Wash Fixture	-	-	-	1	Safety equipment, eye wash, hand held	11 53 33.13 1400	1	EA	$405.00	$405.00
Epoxy Sink	2.3	1.3	0.9	1	Epoxy Resin Sink, 25" x 16" x 10"	11 53 43.13 1610	1	EA	$192.00	$192.00
Sink Base Cabinet	4.0	2.5	3.0	1	Manufactured wood casework- range or sink base, 48" wide	12 32 13.10 1580	1	EA	$355.00	$355.00
1" Epoxy Backsplash	4.0	0.1	0.7	1	Laboratory Countertop, Acid proof Maximum	12 36 53.10 0030	3	SF	$37.50	$112.50
Countertop	4.0	2.5	-	1	Laboratory Countertop, Acid proof Maximum	12 36 53.10 0030	10	SF	$37.50	$375.00
Plant System Peninsula Bench										
Drawer Units 1'9" wide	1.8	2.0	2.8	1	Manufactured Wood Casework Kitchen Base cabinets, 4 drawers, 24" wide	12 32 13.10 1060	1	EA	$345.00	$603.75
Floor Cabinets	1.8	2.0	2.8	1	Manufactured Wood Casework Kitchen Base cabinets, 1 top drawer. 1 drawer below, 21" wide	12 32 13.10 0860	1	EA	$242.00	$242.00
Shelving unit: 1 1/4" particle board with maple vaneer w/ 1/4" solid maple edge banding on all edges	12.7	1.0	-	1	Manufactured Wood Casework Frames, Book cases, one bay, 7' high, 72" wide	12 32 13.15 4000	12	EA	$148.50	$1,782.00
Shelving unit:1" particle board with maple vaneer w/ 3/8" solid maple edge banding on all edges	9.5	1.0	-	1	Manufactured Wood Casework Frames, Book cases, one bay, 7' high, 48" wide	13 32 13.15 3800	12	EA	$121.50	$1,458.00
									Plant Lab Cost	$15,886.39
									ft^2 room	672
									Cost/Ft^2	$23.64
									Total ft^2	59580
									Total Building Interior Cost	$1,408,498.68

Source

1 RSMeans Interior Cost Data 2007
2 RSMeans Construction Cost Data 2007
3 Dennis Coons of Fisher Hamilton

Table 5: Cost Estimate Interior Finishes Summary of Results Part II

Plant System Lab 4212						
Item Description Given in Plans	**Alternative Item Description**	**Source**	**LEED Unit Cost**	**LEED Total Cost**	**Final Cost**	**LEED Qualifiction**
Natural Gas House System	Not Applicable				$88.00	
Lab Vacuum House System	Not Applicable				$176.00	
Vinyl Composition Tile Flooring	Not Applicable				$868.00	
Biology Island Bench						
Drawer Units 1'9" wide	Manufactured Wood Casework Kitchen Base cabinets, 4 drawers, 24" wide	3	$396.75	$2,777.25	$2,777.25	FSC-certified Wood
Floor Cabinets	Manufactured Wood Casework Kitchen Base cabinets, 1 top drawer. 1 drawer below, 21" wide	3	$278.30	$1,113.20	$1,113.20	FSC-certified Wood
Countertop					$2,250.00	
Shelving unit: 1 1/4" particle board with maple vaneer w/ 1/4" solid maple edge banding on all edges	Manufactured Wood Casework Frames, Book cases, one bay, 7' high, 36" wide	3	$92.00	$1,656.00	$1,656.00	FSC-certified Wood
Prefab Electrical Raceway	Not Applicable				$630.00	
Light Fixture under shelf	Not Applicable				$516.00	
Biology Island Bench End Unit						
Shelving unit:1" particle board with maple vaneer w/ 3/8" solid maple edge banding on all edges	Manufactured Wood Casework Frames, Book cases, one bay, 7' high, 36" wide	3	$92.00	$184.00	$184.00	FSC-certified Wood
Adjustable book shelf unit: wood vaneered 1" mdf with 3/8" hardwood edge band	Manufactured Wood Casework Frames, Book cases, one bay, 7' high, 36" wide	3	$92.00	$184.00	$184.00	FSC-certified Wood
Epoxy Resin Countertop	Not Applicable				$337.50	
Corridor Units						
100 lb. Capacity Wood Shelf	Not Applicable				$7.14	
24"x30" Epoxy Peg Board	Not Applicable				$255.00	
Paper Towel Holder	Not Applicable				$39.00	
Soap Dispenser	Not Applicable				$51.50	
Eye Wash Fixture	Not Applicable				$405.00	
Epoxy Sink	Not Applicable				$192.00	
Sink Base Cabinet	Manufactured wood casework- range or sink base, 48" wide	3	$408.25	$408.25	$408.25	FSC-certified Wood
1" Epoxy Backsplash	Not Applicable				$112.50	
Countertop	Not Applicable				$375.00	
Plant System Peninsula Bench						
Drawer Units 1'9" wide	Manufactured Wood Casework Kitchen Base cabinets, 4 drawers, 24" wide	3	$396.75	$694.31	$694.31	FSC-certified Wood
Floor Cabinets	Manufactured Wood Casework Kitchen Base cabinets, 1 top drawer. 1 drawer below, 21" wide	3	$278.30	$278.30	$278.30	FSC-certified Wood
Shelving unit: 1 1/4" particle board with maple vaneer w/ 1/4" solid maple edge banding on all edges	Manufactured Wood Casework Frames, Book cases, one bay, 7' high, 72" wide	3	$170.78	$2,049.30	$2,049.30	FSC-certified Wood
Shelving unit:1" particle board with maple vaneer w/ 3/8" solid maple edge banding on all edges	Manufactured Wood Casework Frames, Book cases, one bay, 7' high, 48" wide	3	$139.73	$1,676.70	$1,676.70	FSC-certified Wood
				Plant Lab Cost	$17,324	
				ft^2 room	672	
				Cost/Ft^2	$25.78	
				Total ft^2	59580	
				Total Building Interior Cost	$1,535,954	

Table 6: Cost Estimate Summary of Results

	Item	Item Description Given in Plans	Source	RSMeans Description	RSMeans Code	Quanity	Unit	Unit Cost	Total Cost	Source	RSMeans Code	LEED Unit Cost	LEED Total Cost	Final Cost	LEED Qualification
Division 3: Concrete															
	Concrete Slab	4 1/2 in. normal weight 3500psi	2	Normal Weight Concrete, ready mix, 3500psi	03 31 05.35 0200	1,417	cy	$106.00	$150,154.23	4	03 31 05.35 0200	$106	$150,154.23	$150,154.23	Local aggregate, sand, portland cement
	WWF	6 x 6 - W2.9 x W2.9 WWF	2	6 x 6 - W2.9 x W2.9 WWF	03 22 05.50 0300	742	csf	$19.80	$14,695.96	4	03 22 05.50 0330	$19.80	$14,695.96	$14,695.96	Post Consumer Recycled Materials
Division 4: Masonry															
	Brick		2	Face brick, standard modular, 4" x 2-2/3" x 8", minimum	04 21 13.45 0300	108	M	$475.00	$51,300.00	5	-	$300.00	$32,400.00	$32,400.00	Reused Materials
	Mortar		2	Mortar with portland cement and lime, type 1:1:6	04 05 13.30 2200	929	cf	$6.00	$5,574.00		Not Applicable			$5,574.00	-
Division 5: Metals															
	Steel Decking	2" x 20 G.A. Galvanized	2	Metal Decking, cellular units, galvanized, 2" deep, 20-20 GA	05 35 13.50 0200	58,568	sf	$6.15	$360,193.20	4	05 35 13.50 0200	$6.15	$360,193.20	$360,193.20	Post Consumer Recycled Materials
	Beams	See "Beams" backup sheet							$600,910.02	4	05 12 23	-	$600,910.02	$600,910.02	Post Consumer Recycled Materials
	Columns	See "Comlumns" backup sheet							$271,830.50	4	6 12 23	-	$271,830.50	$271,830.50	Post Consumer Recycled Materials
Division 7: Thermal and Moisture Protection															
	3.5" Insulation	Acoustic Batt Insulation	2	Wall or Ceiling Insulation, non rigid, fiberglass, unfaced, batts or blankets, 3.5" thick	07 21 16.20 0820	22,692	SF	$0.36	$8,169.12	4	07 21 16 1700	$ 0.66	$ 14,976.72	$ 14,976.72	Post Consumer Recylced Materials
	6" Insulation	Acoustic Batt Insulation	2	Wall or Ceiling Insulation, non rigid, fiberglass, unfaced, batts or blankets, 6" thick	07 21 16.20 0860	6,129	SF	$0.57	$3,493.53	4	07 21 16 1710	$ 0.79	$ 4,841.91	$ 4,841.91	Post Consumer Recycled Materials
	Fireproofing - Beams	Fireproofing for beams (Specifications)	2	Cementious Fireproofing, sprayed mineral fiber or cementious for fireproofing, 1" thick	07 81 16.10 0400	56,862	SF	$0.45	$25,587.90		Not Applicable			$25,587.90	-
	Fireproofing - Columns	Fireproofing for columns (Specifications)	2	Cementious Fireproofing, sprayed mineral fiber or cementious for fireproofing, 1-1/8"" thick	07 81 16.10 0700	8,724	SF	$0.50	$4,362.00		Not Applicable			$4,362.00	-
	Fireproofing - Decking	Fireproofing for steel decking (Specifications)	2	Cementious Fireproofing, sprayed mineral fiber or cementious for fireproofing, for corrugated decking	07 81 16.10 0500	58,568	SF	$0.67	$39,240.56		Not Applicable			$39,240.56	-
	Exterior Wall Rigid Insulation - 2"		2	Fiberglass 1.5#/CF, unfaced, 2" thick, R8.3	07 21 13.10 0080	14,642	SF	$0.68	$9,956.56		Not Applicable			$9,956.56	-
	Roof Rigid Insulation - 2"	1/4" Tapered per foot	2	Fiberboard low density, 2" thick, R5.56	07 22 16.10 0100	8764	SF	$0.84	$7,361.76		Not Applicable			$7,361.76	-
Division 8: Openings															
	Windows	See "Windows & Doors" Backup sheet							$83,127.00		Not Applicable			$83,127.00	-
	Doors	See "Windows & Doors" Backup sheet							$15,768.00		Not Applicable			$15,768.00	-
Division 9: Finishes															
	Paint		2	Concrete, Dry wall or plaster, oil based, primer or sealer coat-spray	09 91 23.72 0280	80,208	SF	$0.04	$3,208.32		Not Applicable			$3,208.32	-
	Gypsum Board	Standard Gypsum Board, 0.625" thick, ASTM C36	2	Gypsum Board, 5/8" thick on walls, fire resistant, taped and finished	09 29 10.30 2150	80,208	SF	$0.42	$33,687.36		5	$ 0.20	$ 16,041.60	$16,041.60	Pre-Consumer Recycled Materials
									$1,688,620					$1,660,230	

Source		
	1	RSMeans Interior Cost Data 2007
	2	RSMeans Construction Cost Data 2007
	4	RSMeans Green Building Cost Data 2007
	5	ReSource Yard

The LEED Materials and Resources category (MR) has one prerequisite and thirteen possible points, focusing on selection of materials and recycling (see Appendix Y for LEED Materials and Resources Category criteria). Of the prerequisite and possible points in the MR category, there were only ten points that were applicable to our project. MR prerequisite 1, *Storage and Collection of Recyclables*, pertains to recycling efforts once the building is occupied. Since our project focuses on the design and construction phases of the facility, we could not evaluate meeting this prerequisite. MR criterion 1.1, 1.2 and 1.3 refer to maintaining a certain percentage of floors and walls for a reused building. Our project focused only on the new portion of the Life Sciences and Bioengineering Center, which was not eligible for these criteria.

The construction of the Bioengineering Center already qualifies for MR criterion 2.1, *Construction Waste Management: Divert 50% from Disposal*. According to Steve Johnson of Consigli Construction Company, Consigli had recycled approximately 56% of the waste produced on the project as of January 31, 2007. This included sixty-one tons of brick, twenty-six tons of wood, seventy-six tons of metal, and sixteen tons of sheetrock. MR criterion 2.2 is an extension of criterion 2.1, requiring 75% of the construction waste to be diverted from disposal. It is unlikely that this project will be able to reach this percentage as it is nearing conclusion.

MR criterion 3.1 requires that reused materials comprise 5% of the total project cost, and criterion 3.2 increases this threshold to 10%. In our estimate, we substituted reused brick, which cost less than new brick. Unfortunately, the cost of the reused brick only constitutes one percent of the total project cost. Therefore, we were unable to obtain the total percentage of reused materials required by MR criterion 3.1 and 3.2. We found the unit price for reused and pre-consumer recycled items from ReSource Yard of Colorado, an organization dedicated to promoting waste reduction by accepting and selling reusable building materials.

Our estimate of this project exceeded MR criterion 4.1 *Recycled Content: 10% (Post-Consumer + ½ Pre-Consumer)* and criterion 4.2 requiring 20% before LEED substitutions were made. To achieve these credits, the project must use recycled materials that reach the required percentage by adding together the post-consumer recycled materials and one half of the pre-consumer recycled materials. Post-consumer recycled materials are defined as materials that require processing to be ready for reuse. Pre-consumer recycled materials do not require reprocessing, such as scrap material that can be reused in its current form. The majority of the post-consumer materials were metals, and the rest consisted of two types of insulation. The 3.5-inch thick insulation was made of recycled glass, and the 6-inch thick insulation was made of recycled blue cotton fibers. The only pre-consumer recycled material was gypsum board, which in our analysis, cost less than purchasing new gypsum board. Overall, the percentage of post-consumer recycled materials plus half of the pre-consumer recycled materials was forty percent, or double the maximum percentage for which a project can receive points. It is likely that the project achieved the maximum percentage of 20% because most steel products contain post-consumer recycled steel.

Aside from reused and recycled materials, regionally extracted materials also promote sustainability in construction. MR criterion 5.1 and 5.2, require that materials be extracted, processed and manufactured within 500 miles of the construction site. MR criterion 5.1 requires that 10% of the materials be obtained regionally, based on cost, while MR criterion 5.2 requires 20%. For this project, information about where materials were extracted, processed and manufactured was difficult to find. While many other materials used in the project may have local origins, we only considered the concrete. The concrete represented 5% of the total cost of the project, which does not meet the requirements of MR criterion 5.1 and 5.2.

MR criterion 6, *Rapidly Renewable Materials*, encourages the use of materials made from plants that have a ten year or less harvest cycle. This includes materials such as bamboo, linoleum, strawboard and cork. For this project, strawboard could have been substituted for gypsum board, but this substitution would not have provided the required 2.5% of the total cost of building materials. It is difficult to substitute other building materials into the design of this facility because of the durability a laboratory space needs, such as acid proof flooring. Therefore, we chose to substitute pre-consumer recycled gypsum board instead of straw board because it was 75% less expensive, as seen in Table 7.

Table 7: Gypsum Board Alternative Prices

Material	Cost/sf
Standard Gypsum Board	$ 0.42
Reused Gypsum Board	$ 0.20
Straw Board	$ 0.80

Certified Wood, the final criterion of the MR category, requires 50% of all wood be Forest Stewardship Council certified wood. The Forest Stewardship Council, an international organization, promotes sustainability through responsibly managed forests (Forest Stewardship Council). By substituting all cabinetry in the project for cabinets made of FSC-certified wood, this project is capable of exceeding MR criterion 7 and reaching 99% of the cost of all wood products.

Overall, if our estimate is accurate, the project would be eligible for four points from the MR category if the substitutions we made were actually implemented. Table 8 summarizes the MR criteria and which criteria were met.

Table 8: Materials and Resources Criteria

No.	MR Criterion	Required	Estimated	Result	Pts
Prerequisite	Storage and Collection of Recyclables	-	-	Not met	-
1.1	Building Reuse: Maintain Walls, Floor & Roof	75%	0%	Not met	0
1.2	Building Reuse: Maintain Walls, Floor & Roof	95%	0%	Not met	0
1.3	Building Reuse: Maintain Interior Non-Structural Elements	50%	0%	Not met	0
2.1	Construction Waste Management: Divert From Disposal	50%	56%	Met	1
2.2	Construction Waste Management: Divert From Disposal	75%	56%	Not met	0
3.1	Material Reuse	5%	1%	Not met	0
3.2	Material Reuse	10%	1%	Not met	0
4.1	Recycled Content	10%	40%	Met	1
4.2	Recycled Content	20%	40%	Met	1
5.1	Regional Materials	10%	5%	Not met	0
5.2	Regional Materials	20%	5%	Not met	0
6	Rapidly Renewable Materials	3%	0%	Not met	0
7	Certified Wood	50%	99%	Met	1
				Total	**4**

Through our cost analysis, we also investigated what materials had the largest effect on the cost of the project. We first compared the estimated cost of the interior finishes to the estimated cost to the other building components. From Figure 14 it is clear that the general building material had the largest impact on the cost.

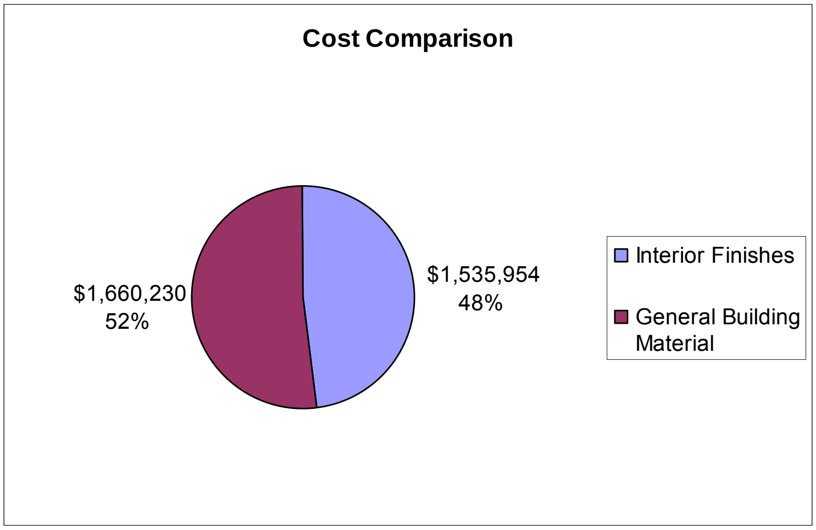

Figure 14: Cost Comparison Pie Chart

We then compared the components in each section of the estimate. We first compared the components of the interior finishes. In our estimate, the laboratory casework was sixty-three percent of the cost. Figure 15 shows the costs of the other major components of the interior finishes cost estimate.

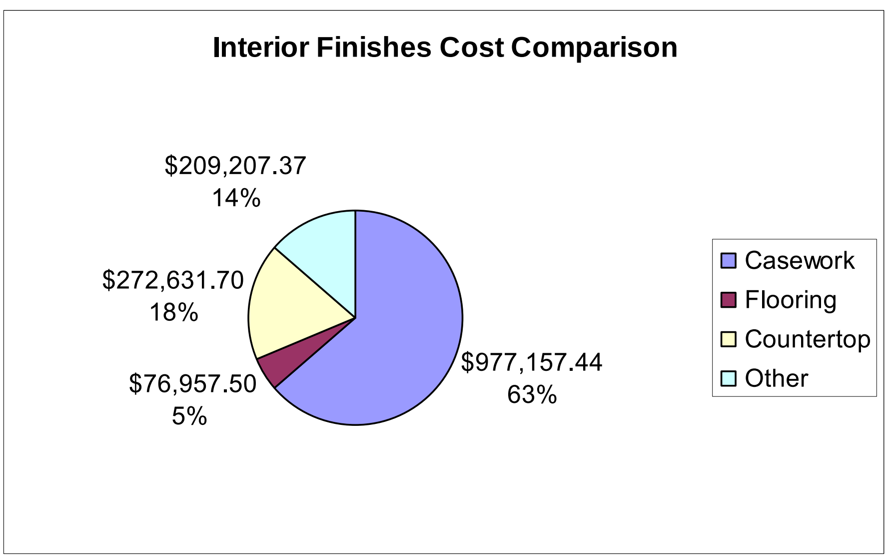

Figure 15: Interior Finishes Cost Comparison Pie Chart

To break down the cost of the elements of the building other than the interior finishes, we broke the cost down by CSI Masterformat division. Figure 16 shows that Division Five, Metals, is seventy-five percent of the cost of the building materials, excluding the interior finishes.

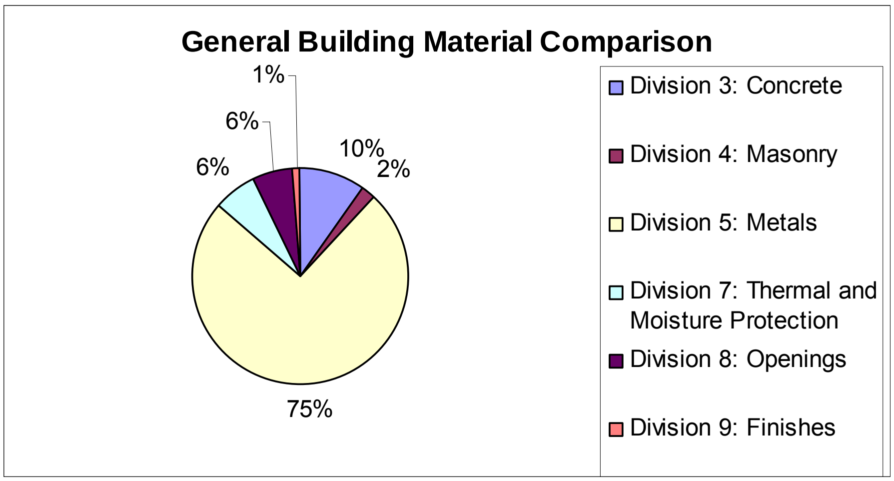

Figure 16: General Building Materials Cost Comparison Pie Chart

4.3 Consigli Owner/Architect Meetings Results

Every week, one member of our project team attended the owner/architect meeting held on site in the Consigli job trailer. Through regular attendance at these meetings we were able to view the construction process from an insider's perspective, which led us to observe several interesting trends. In most cases, these trends were primarily caused either by the actions of representatives from the various companies and organizations involved in the construction of the building, or by the unique nature of the project itself.

The overall attendance at the owner's meeting varied each week, but some organizations were consistently represented by one or more people. For example, Steve

Hebert and/or John Miller typically represented WPI, Brent Arthaud was there every week for the Worcester Business Development Corporation (WBDC), the project engineer, John McDermott, attended regularly, and Brian Hamilton and Steve Johnson from Consigli led each meeting. Other key players in the construction process, such as VanZelm, the MEP consultant, were typically not in attendance.

Each organization that was represented at the meeting played a unique role that typically corresponded with that organization's goals for the project. WPI's representation was heavily involved in making decisions about the building's details. In some instances, it was surprising how many issues still needed to be resolved as the building approached completion. While WPI was also concerned with budget and schedule, representatives of the WBDC, part owner of Gateway Park, paid special attention to change orders and their effect on the budget. They were also very interested in issues related to permitting and meeting the building code, possibly because they wanted the building to pass inspection with as few setbacks as possible, thus minimizing schedule and budget impacts. The people more directly involved with the construction of the project, such as Mr. McDermott, Mr. Johnson, and Mr. Hamilton, were usually answering questions from WPI and WBDC representatives and reporting on the overall status of the project when they spoke.

The nature of the project led to its own set of trends. These trends were caused primarily by the combination of the renovation of a very old building with the construction of an entirely new wing in the same project, and the technical nature of the laboratory facilities that constitute a large part of the new construction. The most significant conflict we observed in the combined renovation/new construction aspect was with the pouring of the concrete slab flooring in the existing building.

When the flooring of the existing building was removed and a new concrete slab was poured, the wood framing flexed in such a way that caused the slab to crack as it dried. The first attempt to repair the cracking failed because the product would not adhere correctly to the concrete and a second contractor was called in to try a different method of repair. After the second attempt to repair the slab, it was deemed acceptable and resolved an issue that had been discussed in the owner's meeting for several weeks. However, as workers finished the flooring in the new portion of the building, they realized that the flooring they were laying would not match the height of the flooring in the existing building, and so the flooring in the existing building had to be sanded down to the correct height.

The characteristics of laboratory construction caused a whole other set of issues. For example, laboratories typically have large quantities of casework for storing supplies, and this casework was a common topic of discussion at the weekly meetings. Representatives from the WBDC and WPI became concerned as the summer came to an end and the building was not yet enclosed because the casework had been delivered and was therefore subject to the humidity of the outside air. This was a concern because the manufacturer's warranty on the casework will become void if it is subject to humidity levels outside of a designated range. However, Consigli project managers acted quickly and took steps to gauge the humidity inside the building each day and make a record of it as a way to ensure the manufacturer that the casework had not been exposed to unacceptable levels of humidity.

5.0 CONCLUSIONS

The summary of our results has led us to develop three sets of conclusions: an evaluation of the alternative roof design, a discussion of the feasibility of building WPI's Life Sciences and Bioengineering Center to meet LEED Materials and Resources criteria, and discussion of the lessons learned from attendance at the owner's meetings. The evaluation of the alternative roof design includes a discussion of the design process, along with the conclusions that were drawn throughout the course of the project that ultimately led us it a new roof design. The discussion of the feasibility of building to LEED standards outlines the points in the Materials and Resources that could have been obtained through the substitutions we evaluated in our cost analysis. The discussion of the conflicts at owner's meetings led us to highlight some important observations we made during this project.

5.1 Evaluation of Alternative Roof Design

Based on the results of our alternative roof design and analysis, we have reached many conclusions about the design process and the procedure necessary to analyze and design a LEED certified roof. Through careful analysis using structural engineering methods established by AISC, we developed a feasible, realistic roof design that is both cost effective and practical in meeting the needs of the existing structure and LEED certification criteria for the heat island effect.

Early in the project, we decided that it would not be realistic to design a vegetated "green roof" in the traditional sense because of the presence of a large number of utilities on the existing roof. Instead we adapted the design to be sloped with roofing materials of an appropriate SRI value. With that information, we came to the conclusion that a steeper sloped roof would be a better option because it required less brick work and was therefore less labor intensive, which would reduce construction costs. LEED requires that a roof with a slope greater than 2:12 have a roofing material with an SRI greater than or equal to twenty-nine. After deciding on a roofing material and slope, we decided on the best arrangement for the framing of the roof given the constraints of the selected roofing material. We concluded that a rafter beam design consisting of W-sections would be too bulky, over designed, and expensive for the comparatively short open spans dictated by the roofing material, so instead, we developed a second option consisting of girders and open-web joists.

After completing our design process, we still ran into some difficulty with fitting the taller mechanical units through openings in the roof and were forced to modify our design slightly. In the end, we concluded that the best design that meets the requirements of the roofing material consists of W21x50 girders running perpendicular to the ridge of the roof and spaced every thirty feet. Additionally, we placed 16K4 joists spaced every 3.5 feet running parallel to the roof's ridge and spanning between the girders. Finally, two W21x44 sill beams run along the eaves of the roof on either side. These sill beams span the columns and transfer the weight of the roofing and framing to the columns. We estimated the cost of materials for this option to be around $127,840.

We also came to many conclusions with respect to the design process itself. All of the little pieces of the puzzle do not always fall into place exactly the way you think they will. Sometimes a design option seems to make sense at first, but through careful consideration of design restrictions, alternate solutions present themselves. This project was no different. Throughout the process of design, we learned to approach problems from different angles in order to ensure that we had chosen the most efficient design possible to meet the needs of the structure. Often, certain assumptions have to be made in design and these assumptions called for various specific considerations. Nothing is ever standardized and every design project has its own unique characteristics with its own needs and idiosyncrasies.

WPI's Life Sciences & Bioengineering Center was no exception, particularly because of our desire to design the building to LEED specifications, which brought up a number of questions. For example, given the extra cost, would it be practical for WPI to have constructed a LEED certified roof? What are the benefits? Are there any savings? These are important questions to ask. Had the existing roof been built to the specifications laid out in our design, WPI's Life Sciences & Bioengineering Center could have gained one more important point toward LEED certification. This is important at WPI because achieving LEED certification protects the environment and preserves natural resources while making a statement to Worcester and the surrounding communities. Complete design and construction of a LEED certified roof like the one we designed for this project would also help to significantly reduce the heat island effect in the cities, which in turn lowers energy usage and cost long term.

More importantly, by reducing the amount of energy consumed by a given building and the buildings around it, environmental resources necessary to produce that energy can be conserved. Though constructing a new roof on the completed laboratory building would not be practical, WPI should consider the effects of conventional roofs on energy usage and resource consumption for future projects, and should remain aware of the benefits of sustainability in construction both long term and short term.

5.2 Feasibility of Meeting LEED Materials and Resources Criteria

From our cost analysis, we are able to conclude that through careful planning and design this project could have received eight of the thirteen points in the LEED Materials and Resources Category and could have met the prerequisite requirement of the Materials and Resources Category. We have also concluded that the difficulties in meeting all of the LEED Materials and Resources categories lie in the durability required by many of the interior finishes and the desire to have a cutting edge facility.

Of the points that we were unable to obtain from our cost estimate, we believe all but two of them would have been obtainable if the project had been designed and planned with LEED objectives in mind. For example, current recycling efforts have exceeded the first LEED goal of 50%. We believe that 75% recycling would have been achievable on this project with the cooperation of all involved parties, which would add an additional point.

It is unlikely that the Bioengineering Center would be able to achieve MR criterion 3.1 and 3.2 regarding reused material. In our analysis, we substituted reused brick. In order to achieve the required percentage for LEED points, some interior finishes would need to be reused materials like cabinets or toilet partitions. It is unlikely that the designers or owners of this facility would want to incorporate used fixtures and furnishings into the interior design for aesthetic reasons.

Careful planning could provide the Center with the opportunity to achieve MR criterion 5.1 and 5.2 concerning regional materials. Many wood products are extracted, processed and manufactured within a five hundred mile radius of Worcester, MA.

Planning with this in mind and a commitment to achieving these criteria regardless of price would have made it easier for this project to obtain points for these criteria.

The final LEED MR criterion that the project would not be able to meet, based on our analysis, was rapidly renewable materials. Based on the way we performed our cost estimate, we did not include any hallway, lobby or office areas. The only interior finishes we estimated were of a typical laboratory space. We then found a cost per square foot of the space and projected the cost of the interior finishes over the entire building. If hallway, lobby and/or office areas were taken into account, other flooring options, such as bamboo or linoleum could have been used. These rapidly renewable materials could have helped achieve MR criterion 7.

The difficulties in achieving all LEED Materials and Resources criteria were the need for high durability materials and the desire to have a cutting edge facility. In laboratory spaces, it is necessary to have highly durable acid proof countertops and flooring, and the latest technology. Overall, the additional cost of building with materials that meet LEED specifications was less then we had originally expected, falling just under one hundred thousand dollars or three percent of the cost of the materials we estimated. The benefits of using materials that are recycled, reused, rapidly renewable, or from responsibly managed forests cannot be measured in cost. This one time expense can be considered the cost for sustainable design and improved quality of life in the building.

5.3 Consigli Owner/Architect Meetings Conclusions

The issues discussed in the results of our attendance at the weekly owner/architect meetings are only some of the many topics that we frequently observed. By seeing how these issues arise and then witnessing their resolutions, we learned much about the construction management process. Unexpected events that will inhibit the project budget or schedule will undoubtedly occur and project managers, owners, and engineers must work together quickly and creatively to develop practical solutions.

Overall, we have found it to be feasible to build the roof of WPI's Life Sciences and Engineering Center to the LEED Heat Island Effect criteria of the Sustainable Sites category and of the center to achieve eleven of the thirteen LEED Materials and Resources points. However, in order to have made that possible, the goal of LEED certification should have been stated at the conception of the project for several reasons. One reason is that the design process is complicated and involved, and LEED criteria should be used as a guideline accompanying regular design specifications in order to avoid costly change orders later in the project. Also, project managers, owners and contractors must be prepared to work together because obtaining LEED certification requires more documentation than a typical project. Additionally, the owner must be willing to incur extra project costs, with the realization that many mechanical, electrical and plumbing alternatives may reap savings in the near future. The designers must be flexible to adapt the design for functionality and material substitutions and the construction managers must be careful to reduce waste and recycle whenever possible.

Issues pertaining to sustainability have come to the forefront of modern concern and must be addressed through widespread participation in sustainable practices. Once

LEED certification is obtained, efforts to improve sustainability and reduce the building's environmental impact are not complete. To maintain the green aspects of the building, the occupants must recognize their contributions to energy usage and waste production, and take measures to reduce them. Once sustainable practices become habit, the ultimate goal of the U.S. Green Building Council's LEED program to become obsolete will be achieved.

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APPENDIX A: Proposal
1.0 Introduction

On March 29, 2005, a $2.5 million grant from the U.S. Economic Development Administration was secured for the development and construction of Gateway Research Park at WPI. Built on 11-acres of redeveloped brownfields land, the focal point of this project has become the newly constructed WPI Life Sciences and Bioengineering Center, which cost around $30 million to build and includes 124,600 square feet of space on four floors at 60 Prescott Street. Built by Consigli Construction Co. of Milford, MA, the facility is now entering its final stages of construction and will soon be occupied by WPI's Bioengineering Institute, which will include many graduate research programs along with outside tenants from the life science field. Though the building site was cleaned up using the appropriate methods, it is important to note that the actual construction of the site was carried out using ordinary construction methods without the use of any green standard (Worcester Polytechnic Institute 1).

The Leadership in Energy and Environmental Design (LEED) standard is a rating system designed to define the term "green building" in a quantitative way by establishing a common measurement universal to all green construction. Standards such as LEED help to ensure that construction methods maintain a minimum degree of sustainability in order to preserve the environment for future generations (U.S. Green Building Council).

The goals of this project are to examine the WPI Life Sciences and Bioengineering Center and determine the feasibility of meeting the LEED certification criteria within the Materials and Resources category and to examine and redesign the roof of the structure to meet the Heat Island Effect criteria laid out in the Sustainable Sites section of the LEED New Construction Standard.

In order to reach these goals we intend to follow a step by step procedure that will allow us to examine different aspects of the building and its construction. First we will carry out an analysis of the materials and resources used in the actual construction with a focus on the cost, availability, and feasibility of their use. This analysis will include developing a cost distribution in order to determine the areas for which the costs are most sensitive. We will follow that up with an analysis of the materials and resources required by LEED standards and do a side by side comparison of the two, paying particular attention to cost and feasibility. This analysis will also be expanded to include long-term maintenance and operation costs. We will simultaneously focus on the roof structure where we will design a new roof that meets LEED Heat Island Effect criteria. Most of our information will be obtained from Consigli Construction Co., archival research, and weekly business meetings. We plan to redesign the roof structure using the engineering techniques acquired through coursework at WPI.

2.0 Literature Review

While the project received a $2.5 million grant from the U.S. Economic Development Administration, there are other forms of government funding that could have potentially been available had the Center been a LEED certified building. The LEED certification program was developed by the U.S. Green Building Council and is intended to raise awareness of issues related to green construction and to create a standard measurement for “green buildings” in order to increase competition for green construction within the industry. A project achieves certification through a process that includes sending project photos, plan sets, typical floor plans, project descriptions and plans outlining how the project will meet the indicated criteria to the U.S. Green Building Council (USGBC).

One might argue that because the WPI Life Sciences & Bioengineering Center will be a laboratory facility, it would be implausible to meet the criteria for LEED certification. However, a case study of the U.S. EPA New England Regional Laboratory suggests otherwise. The Laboratory is a $22 million, 70,400 Sq. Ft. facility located in Chelmsford, MA. To meet LEED criteria in areas such as Land Use and Materials and Resources, the Laboratory includes features such as shower facilities and bicycle storage for bicycle commuters, access to public transportation, the use of steel with the highest possible content of recycled material, and a waste management plan provided by the contractor (U.S. Green Building Council). Among other LEED certified projects, funding has been provided by sources such as the Massachusetts Renewable Energy Trust, Massachusetts Technology Collaborative, and the utility NSTAR.

3.0 Methodology

This project will take three terms to complete and will include a capstone design segment and a comparative cost analysis.

3.1 Determine the Materials and Resources Used in the Current Design of WPI Life Sciences and Bioengineering Center

We plan to begin work on our project through research on the history of Gateway Park and its status as a brownfields site. We will visit the site to view the current construction activity and gain a comprehensive understanding of the project as a whole. We plan to examine drawings and specifications provided by Consigli Construction Co. to determine the current materials used. With this information, a cost distribution of the materials and labor will be developed to determine the most expensive aspects of the project's construction. Correspondence with members of Consigli's construction management team will help us to determine how they are currently disposing of construction waste and if they are reusing any of it. We will maintain our knowledge of WPI Life Sciences and Bioengineering Center by attending weekly owners meetings and compiling meeting minutes.

3.2 Determine the Materials and Resources Needed to Meet LEED Specifications

After we perform archival research on LEED specifications, our focus will narrow to the Materials and Resources category of the LEED Project Checklist. We will research the cost and availability of materials meeting LEED specifications and also determine if they can be directly substituted into the design or if the building needs to be redesigned for LEED compliant materials.

3.3 Analysis of Cost and Availability of Materials

We intend to compare the cost of the materials used in the design of Gateway Park to the cost of alternative materials that meet LEED specifications to determine which materials are least expensive. This analysis will also include long-term maintenance and operation costs.

3.4 Redesign Roof to Meet Heat Island Effect

We plan to redesign the roof to meet the LEED Heat Island Effect specifications. Heat Islands are low-scale temperature differences between rural and urban areas (Environmental Protection Agency). Reducing the Heat Island Effect can reduce energy demands, usage and cost of air conditioning, and the level of air pollution.

We will determine the roof slope of the current design and research roofing materials that meet the required Solar Reflectance Index. Structural engineering techniques will help us determine if the current design can support the roofing materials that meet LEED specification. If the current design does not provide adequate support, we will redesign the structure to support the roof load. We will also experiment with altering the roof slope and other methods to reduce the heat island effect.

Redesigning the roof will include an analysis of the supporting members and require researching the mechanical equipment that is currently located on the roof. We will also evaluate the possibility of moving some equipment to the basement, which may reduce the load on the roof and result in the use of smaller members.

5.0 Project Specification

In order to complete our project we have identified two goals. First, we will examine the WPI Life Sciences and Bioengineering Center and determine the feasibility of meeting all of the LEED certification criteria within the Materials and Resources category. To meet this goal we need to complete the following:

- Determine the cost of the materials and resources used in the actual construction of the Center
- Determine the availability and cost of materials and resources needed to meet LEED specifications
- Determine the maintenance and operation costs for both sets of materials
- Complete a side-by-side comparison of the cost and feasibility for the two construction methods

Secondly, we will examine and redesign the roof of the structure to meet the Heat Island Effect criteria laid out in Sustainable Sites section of the LEED new construction standard. To meet this goal we need to complete the following:

- Analyze the roof structure and materials used
- Redesign roof to meet LEED Heat island effect criteria
- Redesign supporting members to adequately support the revised roof design

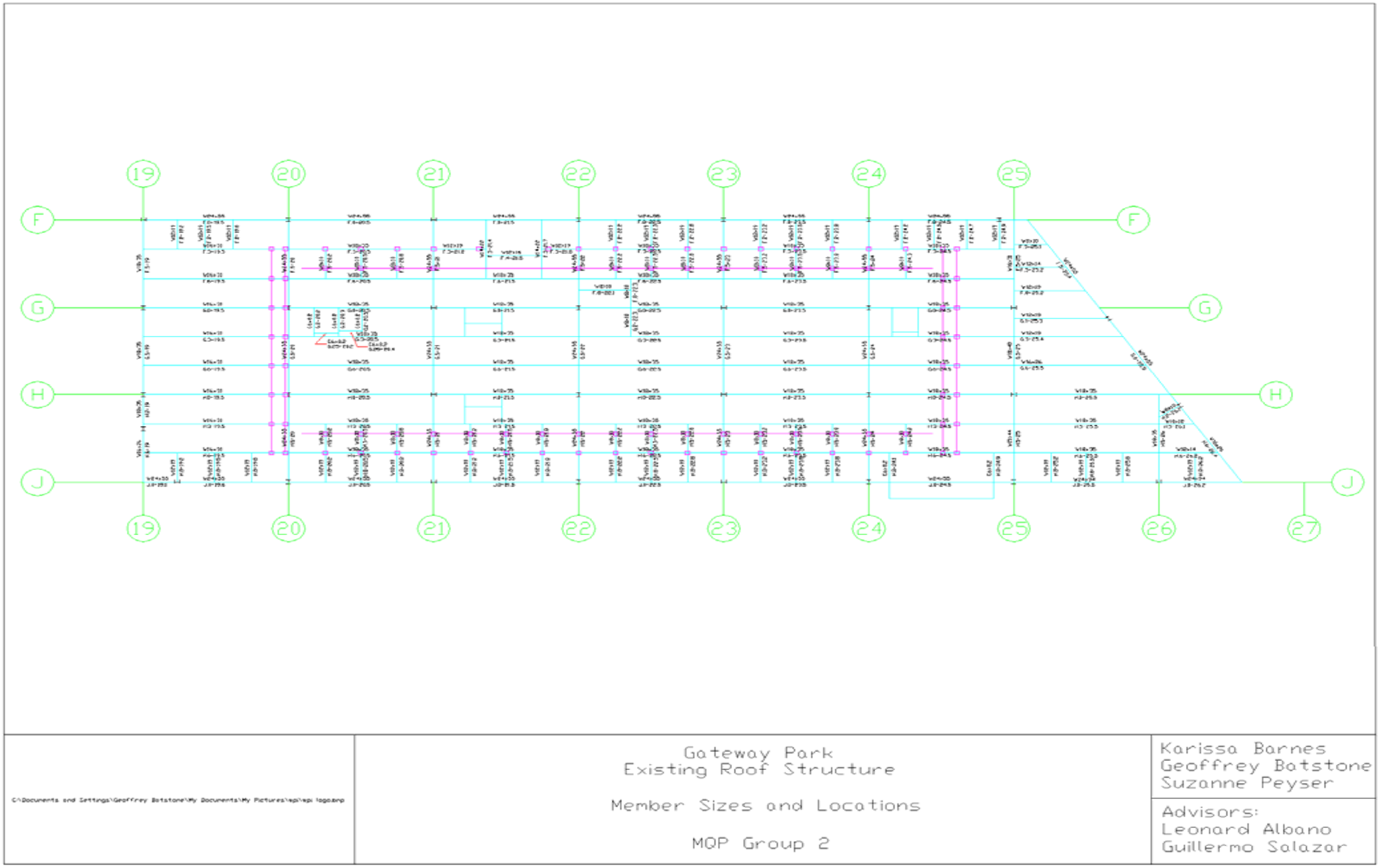
Capstone Design

In order to meet the capstone design requirement of this project we will redesign the roof of the WPI Life Sciences & Bioengineering Center at Gateway Park to meet the Heat Island Effect criteria for LEED standards. Meeting the Heat Island Effect criteria helps to reduce the low-scale temperature differences between rural and urban areas.

Redesigning the roof will include a structural analysis of the existing roof, compiling information about the materials used in the construction of the roof and the purposes they serve. The alternate roof will be sloped, which will require special consideration for the mechanical systems that are currently located on the roof, and constructed with solar reflective material. Additionally, regional codes will be taken into consideration to determine the loads the roof is required to bear.

This project will address economic, environmental, sustainability, manufacturability, and health and safety constraints. We will analyze the costs and benefits of building the WPI Life Sciences & Bioengineering Center to LEED standards to determine if it is economically feasible. Additionally, this design will address environmental and sustainability issues through reducing the building's contribution to increased temperatures in urban areas and energy usage. In terms of manufacturability, our design will include materials that are available regionally and can be assembled with standard construction methods. The design will exceed health and safety constraints because it will meet Massachusetts building codes and lessen the impact of the heat island effect created by the city.

APPENDIX B: Roof Plan



APPENDIX C: Summary of all Member Capacity Checks

Beams

Member	Member Size	Member Weight	Weight Of Concrete Slab (lb/ft^2)	Weight of Steel Decking	Roofing Material (lb/ft^2)	Suspended Services (lb/ft^2)	Ceiling Load (lb/ft^2)	Live Load (lb/ft^2)	Dist. Mechanical Unit Load (lb/ft^2)	Roof Screen Load (lb/ft^2)	T_w (ft)
F.6-19.5	W16x31	31	54.375	2	15	5	5	35	0	5.85	8.00
G.0-19.5	W16x31	31	54.375	2	15	5	5	35	0	5.85	8.00
G.3-19.5	W16x31	31	54.375	2	15	5	5	35	0	5.85	8.00
G.6-19.5	W16x31	31	54.375	2	15	5	5	35	0	5.85	8.00
H.0-19.5	W16x31	31	54.375	2	15	5	5	35	0	5.85	8.00
H.3-19.5	W16x31	31	54.375	2	15	5	5	35	0	5.85	8.00
J.0-19.1	W24x55	55	54.375	2	15	5	5	35	0	0	3.83
F.0-20.5	W24x55	55	54.375	2	15	5	5	35	0	0	3.80
G.0-20.5	W18x35	35	54.375	2	15	5	5	35	67.2	0	8.00
G.3-20.5	W18x35	35	54.375	2	15	5	5	35	67.2	0	8.00
G.6-20.5	W18x35	35	54.375	2	15	5	5	35	67.2	0	8.00
H.0-20.5	W18x35	35	54.375	2	15	5	5	35	67.2	0	8.00
F.3-21.2	W12x19	19	54.375	2	15	5	5	35	0	5.85	7.67
F.4-21.5	W12x16	16	54.375	2	15	5	5	35	0	5.85	7.67
F.3-21.8	W12x19	19	54.375	2	15	5	5	35	0	5.85	7.67
G.0-21.5	W18x35	35	54.375	2	15	5	5	35	67.2	0	8.00
G.3-21.5	W18x35	35	54.375	2	15	5	5	35	67.2	0	8.00
G.6-21.5	W18x35	35	54.375	2	15	5	5	35	67.2	0	8.00
H.0-21.5	W18x35	35	54.375	2	15	5	5	35	67.2	0	8.00
F.8-22.1	W8x10	10	54.375	2	15	5	5	35	67.2	0	3.83
G.6-22.5	W18x35	35	54.375	2	15	5	5	35	67.2	0	8.00
H.0-22.5	W18x35	35	54.375	2	15	5	5	35	67.2	0	8.00
G.0-23.5	W18x35	35	54.375	2	15	5	5	35	67.2	0	8.00
G.3-23.5	W18x35	35	54.375	2	15	5	5	35	67.2	0	8.00
G.6-23.5	W18x35	35	54.375	2	15	5	5	35	67.2	0	8.00
H.0-23.5	W18x35	35	54.375	2	15	5	5	35	67.2	0	8.00
G.0-24.5	W18x35	35	54.375	2	15	5	5	35	67.2	5.85	8.00
G.3-24.5	W18x35	35	54.375	2	15	5	5	35	67.2	5.85	8.00
G.6-24.5	W18x35	35	54.375	2	15	5	5	35	67.2	5.85	8.00
H.0-24.5	W18x35	35	54.375	2	15	5	5	35	67.2	5.85	8.00
F.3-25.1	W8x10	10	54.375	2	15	5	5	35	0	0	6.25
F.5-25.2	W12x14	14	54.375	2	15	5	5	35	0	0	6.00

Member	Member Size	Member Weight	Weight Of Concrete Slab (lb/ft^2)	Weight of Steel Decking	Roofing Material (lb/ft^2)	Suspended Services (lb/ft^2)	Ceiling Load (lb/ft^2)	Live Load (lb/ft^2)	Dist. Mechanical Unit Load (lb/ft^2)	Roof Screen Load (lb/ft^2)	T_w (ft)
F.8-25.2	W12x19	19	54.375	2	15	5	5	35	0	0	6.67
G.1-25.3	W12x19	19	54.375	2	15	5	5	35	0	0	6.10
G.3-25.4	W12x19	19	54.375	2	15	5	5	35	0	0	6.25
G.6-25.5	W16x26	26	54.375	2	15	5	5	35	0	0	7.50
H.0-25.5	W18x35	35	54.375	2	15	5	5	35	0	0	7.40
H.3-25.5	W18x35	35	54.375	2	15	5	5	35	0	0	7.50
H.2-26.1	W8x10	10	54.375	2	15	5	5	35	0	0	5.17
H.3-26.1	W10x12	12	54.375	2	15	5	5	35	0	0	6.20
H.8-19.2	W12x19	19	54.375	2	15	5	5	35	0	0	8.00
H.8-19.5	W12x19	19	54.375	2	15	5	5	35	0	0	8.00
H.8-19.8	W12x19	19	54.375	2	15	5	5	35	0	0	8.00
H.8-20.2	W12x19	19	54.375	2	15	5	5	35	0	0	8.00
H.8-20.5	W12x19	19	54.375	2	15	5	5	35	0	0	8.00
H.8-20.8	W12x19	19	54.375	2	15	5	5	35	0	0	8.00
H.8-21.2	W12x19	19	54.375	2	15	5	5	35	0	0	8.00
H.8-21.5	W12x19	19	54.375	2	15	5	5	35	0	0	8.00
H.8-21.8	W12x19	19	54.375	2	15	5	5	35	0	0	8.00
H.8-22.2	W12x19	19	54.375	2	15	5	5	35	0	0	8.00
H.8-22.5	W12x19	19	54.375	2	15	5	5	35	0	0	8.00
H.8-22.8	W12x19	19	54.375	2	15	5	5	35	0	0	8.00
H.8-23.2	W12x19	19	54.375	2	15	5	5	35	0	0	8.00
H.8-23.5	W12x19	19	54.375	2	15	5	5	35	0	0	8.00
H.8-23.8	W12x19	19	54.375	2	15	5	5	35	0	0	8.00
H.8-24.1	C6x8.2	8.2	54.375	2	15	5	5	35	0	0	8.00
H.8-24.9	C6x8.2	8.2	54.375	2	15	5	5	35	0	0	8.00
H.8-25.2	W12x19	19	54.375	2	15	5	5	35	0	0	8.00
H.8-25.5	W12x19	19	54.375	2	15	5	5	35	0	0	8.00
H.8-25.8	W12x19	19	54.375	2	15	5	5	35	0	0	8.00
H.8-26.2	W12x19	19	54.375	2	15	5	5	35	0	0	8.00
H.5-20.2	W8x10	10	54.375	2	15	5	5	35	67.2	5.85	8.00
H.5-20.5	W8x10	10	54.375	2	15	5	5	35	67.2	5.85	8.00
H.5-20.8	W8x10	10	54.375	2	15	5	5	35	67.2	5.85	8.00
H.5-21.2	W8x10	10	54.375	2	15	5	5	35	67.2	5.85	8.00
H.5-21.5	W8x10	10	54.375	2	15	5	5	35	67.2	5.85	8.00
H.5-21.8	W8x10	10	54.375	2	15	5	5	35	67.2	5.85	8.00
H.5-22.2	W8x10	10	54.375	2	15	5	5	35	67.2	5.85	8.00
H.5-22.5	W8x10	10	54.375	2	15	5	5	35	67.2	5.85	8.00
H.5-22.8	W8x10	10	54.375	2	15	5	5	35	67.2	5.85	8.00

Member	Member Size	Member Weight	Weight Of Concrete Slab (lb/ft^2)	Weight of Steel Decking	Roofing Material (lb/ft^2)	Suspended Services (lb/ft^2)	Ceiling Load (lb/ft^2)	Live Load (lb/ft^2)	Dist. Mechanical Unit Load (lb/ft^2)	Roof Screen Load (lb/ft^2)	T w (ft)
H.5-23.2	W8x10	10	54.375	2	15	5	5	35	67.2	5.85	8.00
H.5-23.5	W8x10	10	54.375	2	15	5	5	35	67.2	5.85	8.00
H.5-23.8	W8x10	10	54.375	2	15	5	5	35	67.2	5.85	8.00
H.5-24.2	W8x10	10	54.375	2	15	5	5	35	67.2	5.85	8.00
G.2-22.3	W8x10	10	54.375	2	15	5	5	35	67.2	0	15.64
F.5-20.2	W8x10	10	54.375	2	15	5	5	35	67.2	5.85	8.00
F.5-20.5	W8x10	10	54.375	2	15	5	5	35	67.2	5.85	8.00
F.5-20.8	W8x10	10	54.375	2	15	5	5	35	67.2	5.85	8.00
F.5-22.2	W8x10	10	54.375	2	15	5	5	35	67.2	5.85	8.00
F.5-22.5	W8x10	10	54.375	2	15	5	5	35	67.2	5.85	8.00
F.5-22.8	W8x10	10	54.375	2	15	5	5	35	67.2	5.85	8.00
F.5-23.2	W8x10	10	54.375	2	15	5	5	35	67.2	5.85	8.00
F.5-23.5	W8x10	10	54.375	2	15	5	5	35	67.2	5.85	8.00
F.5-23.8	W8x10	10	54.375	2	15	5	5	35	67.2	5.85	8.00
F.5-24.3	W8x10	10	54.375	2	15	5	5	35	67.2	5.85	8.00
F.2-19.2	W12x19	19	54.375	2	15	5	5	35	0	0	8.00
F.2-19.5	W12x19	19	54.375	2	15	5	5	35	0	0	8.00
F.2-19.8	W12x19	19	54.375	2	15	5	5	35	0	0	8.00
F.2-22.2	W12x19	19	54.375	2	15	5	5	35	0	0	8.00
F.2-22.5	W12x19	19	54.375	2	15	5	5	35	0	0	8.00
F.2-22.8	W12x19	19	54.375	2	15	5	5	35	0	0	8.00
F.2-23.2	W12x19	19	54.375	2	15	5	5	35	0	0	8.00
F.2-23.5	W12x19	19	54.375	2	15	5	5	35	0	0	8.00
F.2-23.8	W12x19	19	54.375	2	15	5	5	35	0	0	8.00
F.2-24.2	W12x19	19	54.375	2	15	5	5	35	0	0	7.06
F.2-24.5	W12x19	19	54.375	2	15	5	5	35	0	0	7.06
F.2-24.7	W12x19	19	54.375	2	15	5	5	35	0	0	7.06
F.2-24.9	W12x19	19	54.375	2	15	5	5	35	0	0	7.06

Member	Member Size	Member Length (ft)	Member Z_x	Member b_f/2t_f	Member h/t_w	F_y (ksi)	Φ_b	Roof Screen	Dead Load (lb/ft)	Roof Screen Dead Load	Distributed Live Load (lb/ft)	Load Combination W_u (lb/ft)	Roof Screen Design Moment
F.6-19.5	W16x31	31.34	54	6.28	51.6	50	0.9	3	682	75	280	1266	5
G.0-19.5	W16x31	31.34	54	6.28	51.6	50	0.9	3	682	75	280	1266	5
G.3-19.5	W16x31	31.34	54	6.28	51.6	50	0.9	3	682	75	280	1266	5
G.6-19.5	W16x31	31.34	54	6.28	51.6	50	0.9	3	682	75	280	1266	5
H.0-19.5	W16x31	31.34	54	6.28	51.6	50	0.9	3	682	75	280	1266	5
H.3-19.5	W16x31	31.34	54	6.28	51.6	50	0.9	3	682	75	280	1266	5
J.0-19.1	W24x55	7.83	134	6.94	54.6	50	0.9	0	367	0	134	654	0
F.0-20.5	W24x55	31.34	134	6.94	53.5	50	0.9	0	364	0	133	650	0
G.0-20.5	W18x35	31.34	66.5	7.06	53.5	50	0.9	0	1224	0	280	1916	0
G.3-20.5	W18x35	31.34	66.5	7.06	53.5	50	0.9	0	1224	0	280	1916	0
G.6-20.5	W18x35	31.34	66.5	7.06	53.5	50	0.9	0	1224	0	280	1916	0
H.0-20.5	W18x35	31.34	66.5	7.06	53.5	50	0.9	0	1224	0	280	1916	0
F.3-21.2	W12x19	11.33	24.7	5.72	46.2	50	0.9	5	643	72	268	1201	9
F.4-21.5	W12x16	12.00	20.1	7.53	49.4	50	0.9	5	640	72	268	1197	9
F.3-21.8	W12x19	8.00	24.7	5.72	46.2	50	0.9	5	643	72	268	1201	6
G.0-21.5	W18x35	31.34	66.5	7.06	53.5	50	0.9	0	1224	0	280	1916	0
G.3-21.5	W18x35	31.34	66.5	7.06	53.5	50	0.9	0	1224	0	280	1916	0
G.6-21.5	W18x35	31.34	66.5	7.06	53.5	50	0.9	0	1224	0	280	1916	0
H.0-21.5	W18x35	31.34	66.5	7.06	53.5	50	0.9	0	1224	0	280	1916	0
F.8-22.1	W8x10	11.33	8.87	9.61	40.5	50	0.9	0	579	0	134	909	0
G.6-22.5	W18x35	31.34	66.5	7.06	53.5	50	0.9	0	1224	0	280	1916	0
H.0-22.5	W18x35	31.34	66.5	7.06	53.5	50	0.9	0	1224	0	280	1916	0
G.0-23.5	W18x35	31.34	66.5	7.06	53.5	50	0.9	0	1224	0	280	1916	0
G.3-23.5	W18x35	31.34	66.5	7.06	53.5	50	0.9	0	1224	0	280	1916	0
G.6-23.5	W18x35	31.34	66.5	7.06	53.5	50	0.9	0	1224	0	280	1916	0
H.0-23.5	W18x35	31.34	66.5	7.06	53.5	50	0.9	0	1224	0	280	1916	0
G.0-24.5	W18x35	31.34	66.5	7.06	53.5	50	0.9	3	1224	75	280	1916	8
G.3-24.5	W18x35	31.34	66.5	7.06	53.5	50	0.9	3	1224	75	280	1916	8
G.6-24.5	W18x35	31.34	66.5	7.06	53.5	50	0.9	3	1224	75	280	1916	8
H.0-24.5	W18x35	31.34	66.5	7.06	53.5	50	0.9	3	1224	75	280	1916	8
F.3-25.1	W8x10	6.30	8.87	9.61	40.5	50	0.9	0	519	0	219	972	0
F.5-25.2	W12x14	6.40	17.4	8.82	54.3	50	0.9	0	502	0	210	939	0

Member	Member Size	Member Length (ft)	Member Z x	Member b f/2t f	Member h/t w	F y (ksi)	Φ b	Roof Screen	Dead Load (lb/ft)	Roof Screen Dead Load	Distributed Live Load (lb/ft)	Load Combination W u (lb/ft)	Roof Screen Design Moment
F.8-25.2	W12x19	15.42	24.7	5.72	46.2	50	0.9	0	562	0	233	1048	0
G.1-25.3	W12x19	20.42	24.7	5.72	46.2	50	0.9	0	515	0	214	960	0
G.3-25.4	W12x19	23.56	24.7	5.72	46.2	50	0.9	0	528	0	219	983	0
G.6-25.5	W16x26	28.67	44.2	7.97	56.8	50	0.9	0	636	0	263	1184	0
H.0-25.5	W18x35	33.75	66.5	7.06	53.5	50	0.9	0	637	0	259	1179	0
H.3-25.5	W18x35	31.34	66.5	7.06	53.5	50	0.9	0	645	0	263	1194	0
H.2-26.1	W8x10	5.31	8.87	9.61	40.5	50	0.9	0	431	0	181	806	0
H.3-26.1	W10x12	12.76	12.6	9.43	46.6	50	0.9	0	517	0	217	967	0
H.8-19.2	W12x19	7.67	24.7	5.72	46.2	50	0.9	0	670	0	280	1252	0
H.8-19.5	W12x19	7.67	24.7	5.72	46.2	50	0.9	0	670	0	280	1252	0
H.8-19.8	W12x19	7.67	24.7	5.72	46.2	50	0.9	0	670	0	280	1252	0
H.8-20.2	W12x19	7.67	24.7	5.72	46.2	50	0.9	0	670	0	280	1252	0
H.8-20.5	W12x19	7.67	24.7	5.72	46.2	50	0.9	0	670	0	280	1252	0
H.8-20.8	W12x19	7.67	24.7	5.72	46.2	50	0.9	0	670	0	280	1252	0
H.8-21.2	W12x19	7.67	24.7	5.72	46.2	50	0.9	0	670	0	280	1252	0
H.8-21.5	W12x19	7.67	24.7	5.72	46.2	50	0.9	0	670	0	280	1252	0
H.8-21.8	W12x19	7.67	24.7	5.72	46.2	50	0.9	0	670	0	280	1252	0
H.8-22.2	W12x19	7.67	24.7	5.72	46.2	50	0.9	0	670	0	280	1252	0
H.8-22.5	W12x19	7.67	24.7	5.72	46.2	50	0.9	0	670	0	280	1252	0
H.8-22.8	W12x19	7.67	24.7	5.72	46.2	50	0.9	0	670	0	280	1252	0
H.8-23.2	W12x19	7.67	24.7	5.72	46.2	50	0.9	0	670	0	280	1252	0
H.8-23.5	W12x19	7.67	24.7	5.72	46.2	50	0.9	0	670	0	280	1252	0
H.8-23.8	W12x19	7.67	24.7	5.72	46.2	50	0.9	0	670	0	280	1252	0
H.8-24.1	C6x8.2	7.67	5.16	2.80	28.3	50	0.9	0	659	0	280	1239	0
H.8-24.9	C6x8.2	7.67	6.16	2.80	28.3	50	0.9	0	659	0	280	1239	0
H.8-25.2	W12x19	7.67	24.7	5.72	46.2	50	0.9	0	670	0	280	1252	0
H.8-25.5	W12x19	7.67	24.7	5.72	46.2	50	0.9	0	670	0	280	1252	0
H.8-25.8	W12x19	7.67	24.7	5.72	46.2	50	0.9	0	670	0	280	1252	0
H.8-26.2	W12x19	7.67	24.7	5.72	46.2	50	0.9	0	670	0	280	1252	0
H.5-20.2	W8x10	7.67	8.87	9.61	40.5	50	0.9	3	1199	75	280	1886	5
H.5-20.5	W8x10	7.67	8.87	9.61	40.5	50	0.9	3	1199	75	280	1886	5
H.5-20.8	W8x10	7.67	8.87	9.61	40.5	50	0.9	3	1199	75	280	1886	5
H.5-21.2	W8x10	7.67	8.87	9.61	40.5	50	0.9	3	1199	75	280	1886	5
H.5-21.5	W8x10	7.67	8.87	9.61	40.5	50	0.9	3	1199	75	280	1886	5
H.5-21.8	W8x10	7.67	8.87	9.61	40.5	50	0.9	3	1199	75	280	1886	5
H.5-22.2	W8x10	7.67	8.87	9.61	40.5	50	0.9	3	1199	75	280	1886	5
H.5-22.5	W8x10	7.67	8.87	9.61	40.5	50	0.9	3	1199	75	280	1886	5
H.5-22.8	W8x10	7.67	8.87	9.61	40.5	50	0.9	3	1199	75	280	1886	5

Member	Member Size	Member Length (ft)	Member Z_x	Member b_f/2t_f	Member h/t_w	F_y (ksi)	Φ_b	Roof Screen	Dead Load (lb/ft)	Roof Screen Dead Load	Distributed Live Load (lb/ft)	Load Combination W_u (lb/ft)	Roof Screen Design Momen
H.5-23.2	W8x10	7.67	8.87	9.61	40.5	50	0.9	3	1199	75	280	1886	5
H.5-23.5	W8x10	7.67	8.87	9.61	40.5	50	0.9	3	1199	75	280	1886	5
H.5-23.8	W8x10	7.67	8.87	9.61	40.5	50	0.9	3	1199	75	280	1886	5
H.5-24.2	W8x10	7.67	8.87	9.61	40.5	50	0.9	3	1199	75	280	1886	5
G.2-22.3	W8x10	7.67	8.87	9.61	40.5	50	0.9	0	2334	0	547	3676	0
F.5-20.2	W8x10	7.67	8.87	9.61	40.5	50	0.9	3	1199	75	280	1886	5
F.5-20.5	W8x10	7.67	8.87	9.61	40.5	50	0.9	3	1199	75	280	1886	5
F.5-20.8	W8x10	7.67	8.87	9.61	40.5	50	0.9	3	1199	75	280	1886	5
F.5-22.2	W8x10	7.67	8.87	9.61	40.5	50	0.9	3	1199	75	280	1886	5
F.5-22.5	W8x10	7.67	8.87	9.61	40.5	50	0.9	3	1199	75	280	1886	5
F.5-22.8	W8x10	7.67	8.87	9.61	40.5	50	0.9	3	1199	75	280	1886	5
F.5-23.2	W8x10	7.67	8.87	9.61	40.5	50	0.9	3	1199	75	280	1886	5
F.5-23.5	W8x10	7.67	8.87	9.61	40.5	50	0.9	3	1199	75	280	1886	5
F.5-23.8	W8x10	7.67	8.87	9.61	40.5	50	0.9	3	1199	75	280	1886	5
F.5-24.3	W8x10	7.67	8.87	9.61	40.5	50	0.9	3	1199	75	280	1886	5
F.2-19.2	W12x19	7.67	24.7	5.72	46.2	50	0.9	0	670	0	280	1252	0
F.2-19.5	W12x19	7.67	24.7	5.72	46.2	50	0.9	0	670	0	280	1252	0
F.2-19.8	W12x19	7.67	24.7	5.72	46.2	50	0.9	0	670	0	280	1252	0
F.2-22.2	W12x19	7.67	24.7	5.72	46.2	50	0.9	0	670	0	280	1252	0
F.2-22.5	W12x19	7.67	24.7	5.72	46.2	50	0.9	0	670	0	280	1252	0
F.2-22.8	W12x19	7.67	24.7	5.72	46.2	50	0.9	0	670	0	280	1252	0
F.2-23.2	W12x19	7.67	24.7	5.72	46.2	50	0.9	0	670	0	280	1252	0
F.2-23.5	W12x19	7.67	24.7	5.72	46.2	50	0.9	0	670	0	280	1252	0
F.2-23.8	W12x19	7.67	24.7	5.72	46.2	50	0.9	0	670	0	280	1252	0
F.2-24.2	W12x19	7.67	24.7	5.72	46.2	50	0.9	0	594	0	247	1108	0
F.2-24.5	W12x19	7.67	24.7	5.72	46.2	50	0.9	0	594	0	247	1108	0
F.2-24.7	W12x19	7.67	24.7	5.72	46.2	50	0.9	0	594	0	247	1108	0
F.2-24.9	W12x19	7.67	24.7	5.72	46.2	50	0.9	0	594	0	247	1108	0

Member	Member Size	Other Load Design Moment	Total Design Moment M_u ft	ΦM_p	Required Z_x (in^3)	Adequate Z_x?	b_f/2t_f≤9.2?	h/t_w≤90.5?	Use plastic capacity check?	ΦM_p> M_u?	Adequate beam size?	F_r
F.6-19.5	W16x31	155	161	203	42.8	yes	yes	yes	yes	yes	yes	
G.0-19.5	W16x31	155	161	203	42.8	yes	yes	yes	yes	yes	yes	
G.3-19.5	W16x31	155	161	203	42.8	yes	yes	yes	yes	yes	yes	
G.6-19.5	W16x31	155	161	203	42.8	yes	yes	yes	yes	yes	yes	
H.0-19.5	W16x31	155	161	203	42.8	yes	yes	yes	yes	yes	yes	
H.3-19.5	W16x31	155	161	203	42.8	yes	yes	yes	yes	yes	yes	
J.0-19.1	W24x55	5	5	503	1.3	yes	yes	yes	yes	yes	yes	
F.0-20.5	W24x55	80	80	503	21.3	yes	yes	yes	yes	yes	yes	
G.0-20.5	W18x35	235	235	249	62.7	yes	yes	yes	yes	yes	yes	
G.3-20.5	W18x35	235	235	249	62.7	yes	yes	yes	yes	yes	yes	
G.6-20.5	W18x35	235	235	249	62.7	yes	yes	yes	yes	yes	yes	
H.0-20.5	W18x35	235	235	249	62.7	yes	yes	yes	yes	yes	yes	
F.3-21.2	W12x19	19	28	93	7.4	yes	yes	yes	yes	yes	yes	
F.4-21.5	W12x16	22	30	75	8.1	yes	yes	yes	yes	yes	yes	
F.3-21.8	W12x19	10	15	93	4.1	yes	yes	yes	yes	yes	yes	
G.0-21.5	W18x35	235	235	249	62.7	yes	yes	yes	yes	yes	yes	
G.3-21.5	W18x35	235	235	249	62.7	yes	yes	yes	yes	yes	yes	
G.6-21.5	W18x35	235	235	249	62.7	yes	yes	yes	yes	yes	yes	
H.0-21.5	W18x35	235	235	249	62.7	yes	yes	yes	yes	yes	yes	
F.8-22.1	W8x10	15	15	33	3.9	yes	no	yes	no	-	Use inelastic check	10
G.6-22.5	W18x35	235	235	249	62.7	yes	yes	yes	yes	yes	yes	
H.0-22.5	W18x35	235	235	249	62.7	yes	yes	yes	yes	yes	yes	
G.0-23.5	W18x35	235	235	249	62.7	yes	yes	yes	yes	yes	yes	
G.3-23.5	W18x35	235	235	249	62.7	yes	yes	yes	yes	yes	yes	
G.6-23.5	W18x35	235	235	249	62.7	yes	yes	yes	yes	yes	yes	
H.0-23.5	W18x35	235	235	249	62.7	yes	yes	yes	yes	yes	yes	
G.0-24.5	W18x35	235	243	249	64.8	yes	yes	yes	yes	yes	yes	
G.3-24.5	W18x35	235	243	249	64.8	yes	yes	yes	yes	yes	yes	
G.6-24.5	W18x35	235	243	249	64.8	yes	yes	yes	yes	yes	yes	
H.0-24.5	W18x35	235	243	249	64.8	yes	yes	yes	yes	yes	yes	
F.3-25.1	W8x10	5	5	33	1.3	yes	no	yes	no	-	Use inelastic check	10
F.5-25.2	W12x14	5	5	65	1.3	yes	yes	yes	yes	yes	yes	

Member	Member Size	Other Load Design Moment	Total Design Moment M_u ft	ΦM_p	Required Z_x (in^3)	Adequate Z_x?	b_f/2t_f≤9.2?	h/t_w≤90.5?	Use plastic capacity check?	ΦM_p> M_u?	Adequate beam size?	F_r
F.8-25.2	W12x19	31	31	93	8.3	yes	yes	yes	yes	yes	yes	
G.1-25.3	W12x19	50	50	93	13.3	yes	yes	yes	yes	yes	yes	
G.3-25.4	W12x19	68	68	93	18.2	yes	yes	yes	yes	yes	yes	
G.6-25.5	W16x26	122	122	166	32.4	yes	yes	yes	yes	yes	yes	
H.0-25.5	W18x35	168	168	249	44.8	yes	yes	yes	yes	yes	yes	
H.3-25.5	W18x35	147	147	249	39.1	yes	yes	yes	yes	yes	yes	
H.2-26.1	W8x10	3	3	33	0.8	yes	no	yes	no	-	Use inelastic check	10
H.3-26.1	W10x12	20	20	47	5.2	yes	no	yes	no	-	Use inelastic check	10
H.8-19.2	W12x19	9	9	93	2.5	yes	yes	yes	yes	yes	yes	
H.8-19.5	W12x19	9	9	93	2.5	yes	yes	yes	yes	yes	yes	
H.8-19.8	W12x19	9	9	93	2.5	yes	yes	yes	yes	yes	yes	
H.8-20.2	W12x19	9	9	93	2.5	yes	yes	yes	yes	yes	yes	
H.8-20.5	W12x19	9	9	93	2.5	yes	yes	yes	yes	yes	yes	
H.8-20.8	W12x19	9	9	93	2.5	yes	yes	yes	yes	yes	yes	
H.8-21.2	W12x19	9	9	93	2.5	yes	yes	yes	yes	yes	yes	
H.8-21.5	W12x19	9	9	93	2.5	yes	yes	yes	yes	yes	yes	
H.8-21.8	W12x19	9	9	93	2.5	yes	yes	yes	yes	yes	yes	
H.8-22.2	W12x19	9	9	93	2.5	yes	yes	yes	yes	yes	yes	
H.8-22.5	W12x19	9	9	93	2.5	yes	yes	yes	yes	yes	yes	
H.8-22.8	W12x19	9	9	93	2.5	yes	yes	yes	yes	yes	yes	
H.8-23.2	W12x19	9	9	93	2.5	yes	yes	yes	yes	yes	yes	
H.8-23.5	W12x19	9	9	93	2.5	yes	yes	yes	yes	yes	yes	
H.8-23.8	W12x19	9	9	93	2.5	yes	yes	yes	yes	yes	yes	
H.8-24.1	C6x8.2	9	9	19	2.4	yes	yes	yes	yes	yes	yes	
H.8-24.9	C6x8.2	9	9	23	2.4	yes	yes	yes	yes	yes	yes	
H.8-25.2	W12x19	9	9	93	2.5	yes	yes	yes	yes	yes	yes	
H.8-25.5	W12x19	9	9	93	2.5	yes	yes	yes	yes	yes	yes	
H.8-25.8	W12x19	9	9	93	2.5	yes	yes	yes	yes	yes	yes	
H.8-26.2	W12x19	9	9	93	2.5	yes	yes	yes	yes	yes	yes	
H.5-20.2	W8x10	14	19	33	5.1	yes	no	yes	no	-	Use inelastic check	10
H.5-20.5	W8x10	14	19	33	5.1	yes	no	yes	no	-	Use inelastic check	10
H.5-20.8	W8x10	14	19	33	5.1	yes	no	yes	no	-	Use inelastic check	10
H.5-21.2	W8x10	14	19	33	5.1	yes	no	yes	no	-	Use inelastic check	10
H.5-21.5	W8x10	14	19	33	5.1	yes	no	yes	no	-	Use inelastic check	10
H.5-21.8	W8x10	14	19	33	5.1	yes	no	yes	no	-	Use inelastic check	10
H.5-22.2	W8x10	14	19	33	5.1	yes	no	yes	no	-	Use inelastic check	10
H.5-22.5	W8x10	14	19	33	5.1	yes	no	yes	no	-	Use inelastic check	10
H.5-22.8	W8x10	14	19	33	5.1	yes	no	yes	no	-	Use inelastic check	10

Member	Member Size	Other Load Design Moment	Total Design Moment M_u ft	ΦM_p	Required Z_x (in^3)	Adequate Z_x?	b_f/2t_f≤9.2?	h/t_w≤90.5?	Use plastic capacity check?	ΦM_p> M_u?	Adequate beam size?	F_r
H.5-23.2	W8x10	14	19	33	5.1	yes	no	yes	no	-	Use inelastic check	10
H.5-23.5	W8x10	14	19	33	5.1	yes	no	yes	no	-	Use inelastic check	10
H.5-23.8	W8x10	14	19	33	5.1	yes	no	yes	no	-	Use inelastic check	10
H.5-24.2	W8x10	14	19	33	5.1	yes	no	yes	no	-	Use inelastic check	10
G.2-22.3	W8x10	27	27	33	7.2	yes	no	yes	no	-	Use inelastic check	10
F.5-20.2	W8x10	14	19	33	5.1	yes	no	yes	no	-	Use inelastic check	10
F.5-20.5	W8x10	14	19	33	5.1	yes	no	yes	no	-	Use inelastic check	10
F.5-20.8	W8x10	14	19	33	5.1	yes	no	yes	no	-	Use inelastic check	10
F.5-22.2	W8x10	14	19	33	5.1	yes	no	yes	no	-	Use inelastic check	10
F.5-22.5	W8x10	14	19	33	5.1	yes	no	yes	no	-	Use inelastic check	10
F.5-22.8	W8x10	14	19	33	5.1	yes	no	yes	no	-	Use inelastic check	10
F.5-23.2	W8x10	14	19	33	5.1	yes	no	yes	no	-	Use inelastic check	10
F.5-23.5	W8x10	14	19	33	5.1	yes	no	yes	no	-	Use inelastic check	10
F.5-23.8	W8x10	14	19	33	5.1	yes	no	yes	no	-	Use inelastic check	10
F.5-24.3	W8x10	14	19	33	5.1	yes	no	yes	no	-	Use inelastic check	10
F.2-19.2	W12x19	9	9	93	2.5	yes	yes	yes	yes	yes	yes	
F.2-19.5	W12x19	9	9	93	2.5	yes	yes	yes	yes	yes	yes	
F.2-19.8	W12x19	9	9	93	2.5	yes	yes	yes	yes	yes	yes	
F.2-22.2	W12x19	9	9	93	2.5	yes	yes	yes	yes	yes	yes	
F.2-22.5	W12x19	9	9	93	2.5	yes	yes	yes	yes	yes	yes	
F.2-22.8	W12x19	9	9	93	2.5	yes	yes	yes	yes	yes	yes	
F.2-23.2	W12x19	9	9	93	2.5	yes	yes	yes	yes	yes	yes	
F.2-23.5	W12x19	9	9	93	2.5	yes	yes	yes	yes	yes	yes	
F.2-23.8	W12x19	9	9	93	2.5	yes	yes	yes	yes	yes	yes	
F.2-24.2	W12x19	8	8	93	2.2	yes	yes	yes	yes	yes	yes	
F.2-24.5	W12x19	8	8	93	2.2	yes	yes	yes	yes	yes	yes	
F.2-24.7	W12x19	8	8	93	2.2	yes	yes	yes	yes	yes	yes	
F.2-24.9	W12x19	8	8	93	2.2	yes	yes	yes	yes	yes	yes	

Member	Member Size	F_L	S_x	F_L*S_x	λ_p	λ_r	Capacity M_n	ΦM_n/M_u	Adequate beam size?
F.6-19.5	W16x31								
G.0-19.5	W16x31								
G.3-19.5	W16x31								
G.6-19.5	W16x31								
H.0-19.5	W16x31								
H.3-19.5	W16x31								
J.0-19.1	W24x55								
F.0-20.5	W24x55								
G.0-20.5	W18x35								
G.3-20.5	W18x35								
G.6-20.5	W18x35								
H.0-20.5	W18x35								
F.3-21.2	W12x19								
F.4-21.5	W12x16								
F.3-21.8	W12x19								
G.0-21.5	W18x35								
G.3-21.5	W18x35								
G.6-21.5	W18x35								
H.0-21.5	W18x35								
F.8-22.1	W8x10	40	7.81	312.4	9.2	90.5	31.9	2.2	yes
G.6-22.5	W18x35								
H.0-22.5	W18x35								
G.0-23.5	W18x35								
G.3-23.5	W18x35								
G.6-23.5	W18x35								
H.0-23.5	W18x35								
G.0-24.5	W18x35								
G.3-24.5	W18x35								
G.6-24.5	W18x35								
H.0-24.5	W18x35								
F.3-25.1	W8x10	40	7.81	312.4	9.2	90.5	31.9	6.6	yes
F.5-25.2	W12x14								

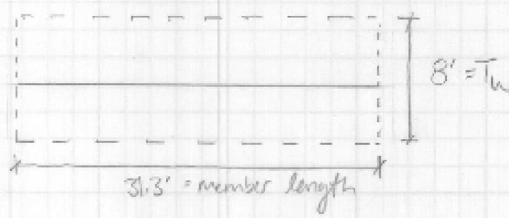
Member	Member Size	F L	S x	F L*S x	λ p	λ r	Capacity M n	ΦM n/M u	Adequate beam size?
F.8-25.2	W12x19								
G.1-25.3	W12x19								
G.3-25.4	W12x19								
G.6-25.5	W16x26								
H.0-25.5	W18x35								
H.3-25.5	W18x35								
H.2-26.1	W8x10	40	7.81	312.4	9.2	90.5	31.9	11.2	yes
H.3-26.1	W10x12	40	10.9	436	9.2	90.5	46.2	2.3	yes
H.8-19.2	W12x19								
H.8-19.5	W12x19								
H.8-19.8	W12x19								
H.8-20.2	W12x19								
H.8-20.5	W12x19								
H.8-20.8	W12x19								
H.8-21.2	W12x19								
H.8-21.5	W12x19								
H.8-21.8	W12x19								
H.8-22.2	W12x19								
H.8-22.5	W12x19								
H.8-22.8	W12x19								
H.8-23.2	W12x19								
H.8-23.5	W12x19								
H.8-23.8	W12x19								
H.8-24.1	C6x8.2								
H.8-24.9	C6x8.2								
H.8-25.2	W12x19								
H.8-25.5	W12x19								
H.8-25.8	W12x19								
H.8-26.2	W12x19								
H.5-20.2	W8x10	40	7.81	312.4	9.2	90.5	31.9	1.7	yes
H.5-20.5	W8x10	40	7.81	312.4	9.2	90.5	31.9	1.7	yes
H.5-20.8	W8x10	40	7.81	312.4	9.2	90.5	31.9	1.7	yes
H.5-21.2	W8x10	40	7.81	312.4	9.2	90.5	31.9	1.7	yes
H.5-21.5	W8x10	40	7.81	312.4	9.2	90.5	31.9	1.7	yes
H.5-21.8	W8x10	40	7.81	312.4	9.2	90.5	31.9	1.7	yes
H.5-22.2	W8x10	40	7.81	312.4	9.2	90.5	31.9	1.7	yes
H.5-22.5	W8x10	40	7.81	312.4	9.2	90.5	31.9	1.7	yes
H.5-22.8	W8x10	40	7.81	312.4	9.2	90.5	31.9	1.7	yes

Member	Member Size	F_L	S_x	F_L*S_x	λ_p	λ_r	Capacity M_n	$\Phi M_n/M_u$	Adequate beam size?
H.5-23.2	W8x10	40	7.81	312.4	9.2	90.5	31.9	1.7	yes
H.5-23.5	W8x10	40	7.81	312.4	9.2	90.5	31.9	1.7	yes
H.5-23.8	W8x10	40	7.81	312.4	9.2	90.5	31.9	1.7	yes
H.5-24.2	W8x10	40	7.81	312.4	9.2	90.5	31.9	1.7	yes
G.2-22.3	W8x10	40	7.81	312.4	9.2	90.5	31.9	1.2	yes
F.5-20.2	W8x10	40	7.81	312.4	9.2	90.5	31.9	1.7	yes
F.5-20.5	W8x10	40	7.81	312.4	9.2	90.5	31.9	1.7	yes
F.5-20.8	W8x10	40	7.81	312.4	9.2	90.5	31.9	1.7	yes
F.5-22.2	W8x10	40	7.81	312.4	9.2	90.5	31.9	1.7	yes
F.5-22.5	W8x10	40	7.81	312.4	9.2	90.5	31.9	1.7	yes
F.5-22.8	W8x10	40	7.81	312.4	9.2	90.5	31.9	1.7	yes
F.5-23.2	W8x10	40	7.81	312.4	9.2	90.5	31.9	1.7	yes
F.5-23.5	W8x10	40	7.81	312.4	9.2	90.5	31.9	1.7	yes
F.5-23.8	W8x10	40	7.81	312.4	9.2	90.5	31.9	1.7	yes
F.5-24.3	W8x10	40	7.81	312.4	9.2	90.5	31.9	1.7	yes
F.2-19.2	W12x19								
F.2-19.5	W12x19								
F.2-19.8	W12x19								
F.2-22.2	W12x19								
F.2-22.5	W12x19								
F.2-22.8	W12x19								
F.2-23.2	W12x19								
F.2-23.5	W12x19								
F.2-23.8	W12x19								
F.2-24.2	W12x19								
F.2-24.5	W12x19								
F.2-24.7	W12x19								
F.2-24.9	W12x19								

APPENDIX D: Typical Beam Calculation

Typical Beam Calc - No Roof Screen Load, with Mechanical unit load

Member: G.0-20.5 Member size: W18×35



Assumptions
- → Ponding and wind loads are negligible
- → f_y = 50 ksi
- → pinned-pinned connections
- → full lateral support

weight of conc. slab = $\frac{145 \text{ lb}}{\text{ft}^3}$ (.375 ft) = 54.375 lbs/ft² (weight, depth)

dead load = [(wt. of decking) + (wt. of conc) + (wt. roof material) + (wt. suspended services) + (wt. ceiling load) + (mech. unit load)] T_w + 35 lb/ft

= [(2 lb/ft²) + (54.375 lb/ft²) + (15 lb/ft²) + (5 lb/ft²) + (5 lb/ft²) + (67.2 lb/ft²)] 8 + 35 lb/ft = 1223.6 lb/ft

roof live load ⇒ snow load governs = 35 lbs/ft²

LL_{roof} = 35 lbs/ft² (8 ft) = 280 lbs/ft

Load Combinations

1) 1.4D = 1.4(1223.6 lb/ft) = 1713 lb/ft
2) 1.2D + 1.6L_{roof} = 1.2(1713) + 1.6(280) = 1916 lb/ft

W_u = 1916 lb/ft

Design Moment

$M_{u\,\text{pinned-pinned}} = \frac{W_u L^2}{8} = \frac{1916(31.3)^2}{8}$ = 235 ft·kips

Req'd Z_x

$Z_x \geq \frac{M_u}{\Phi_b = .9 F_y} = \frac{235 \text{ ft kips}(12 \text{ inches})}{.9(50 \text{ ksi})}$ = 62.67 in³

Z_x of W18×35 = 66.5 in³ ✓ok

$\frac{b_f}{2t_f}$ of W18×35 > 9.2?

$\frac{h}{t_w}$ of W18×35 > 90.5?

Find Plastic Capacity

$\phi M_p = \phi_b Z_x F_y = .9(66.5)(50)(1/12) = 250 \text{ ft k}$

$\phi M_p = 250 \text{ ft k} > M_u = 235 \text{ ft·k}$ ✓ok

APPENDIX E: Type I Girder Calculations

Type 1: The Girder supports adjacent beams for the entire girders tributary area.

Member	Member Size	Member Weight (lb/ft)	Weight Of Concrete Slab (lb/ft^2)	Weight of Steel Decking (lb/ft^2)	Roofing Material (lb/ft^2)	Suspended Services (lb/ft^2)	Ceiling Load (lb/ft^2)
J.0-19.6	W24x55	55	54.375	2	15	5	5
J.0-20.5	W24x55	55	54.375	2	15	5	5
J.0-21.5	W24x55	55	54.375	2	15	5	5
J.0-22.5	W24x55	55	54.375	2	15	5	5
J.0-23.5	W24x55	55	54.375	2	15	5	5
J.0-24.5	W24x55	55	54.375	2	15	5	5
J.0-25.5	W24x94	94	54.375	2	15	5	5
J.0-26.2	W24x94	94	54.375	2	15	5	5
H.6-20.5	W18x35	35	54.375	2	15	5	5
H.6-21.5	W18x35	35	54.375	2	15	5	5
H.6-22.5	W18x35	35	54.375	2	15	5	5
H.6-23.5	W18x35	35	54.375	2	15	5	5
F.3-22.5	W18X35	35	54.375	2	15	5	5
F.3-23.5	W18X35	35	54.375	2	15	5	5
F.3-24.5	W18X35	35	54.375	2	15	5	5
F.0-19.5	W24x55	55	54.375	2	15	5	5
F.0-21.5	W24x55	55	54.375	2	15	5	5
F.0-22.5	W24x55	55	54.375	2	15	5	5
F.0-23.5	W24x55	55	54.375	2	15	5	5
F.0-24.5	W24x55	55	54.375	2	15	5	5
H.2-19	W18x35	35	54.375	2	15	5	5
G.5-19	W18x35	35	54.375	2	15	5	5
G.5-20	W24x55	55	54.375	2	15	5	5
G.5-21	W24x55	55	54.375	2	15	5	5
G.5-22	W24x55	55	54.375	2	15	5	5
G.5-23	W24x55	55	54.375	2	15	5	5
G.5-24	W24x55	55	54.375	2	15	5	5
G.5-25	W18x40	40	54.375	2	15	5	5
G.6-25.9	W24x55	55	54.375	2	15	5	5
F.3-21.4	W14x22	22	54.375	2	15	5	5
F.3-21.7	W14x22	22	54.375	2	15	5	5

Type 1: The Girder suppc							
Member	Member Size	Live Load (lb/ft^2)	Ave. Nominal Adjacent Beam	Number of Beam Tributary Widths	Dist. Mechanical Unit Load (lb/ft^2)	Roof Screen Load (lb/ft^2)	T_w (ft) Girder
J.0-19.6	W24x55	35	19	3	0	0	3.83
J.0-20.5	W24x55	35	19	4	0	0	3.83
J.0-21.5	W24x55	35	19	4	0	0	3.83
J.0-22.5	W24x55	35	19	4	0	0	3.83
J.0-23.5	W24x55	35	19	4	0	0	3.83
J.0-24.5	W24x55	35	8.2	3	0	0	3.83
J.0-25.5	W24x94	35	19	4	0	0	3.83
J.0-26.2	W24x94	35	19	2	0	0	3.83
H.6-20.5	W18x35	35	14.5	4	0	5.85	7.67
H.6-21.5	W18x35	35	14.5	4	0	5.85	7.67
H.6-22.5	W18x35	35	14.5	4	0	5.85	7.67
H.6-23.5	W18x35	35	14.5	4	0	5.85	7.67
F.3-22.5	W18X35	35	14.5	4	0	5.85	7.67
F.3-23.5	W18X35	35	14.5	4	0	5.85	7.67
F.3-24.5	W18X35	35	17.2	4	0	5.85	7.67
F.0-19.5	W24x55	35	19	4	0	0	3.83
F.0-21.5	W24x55	35	22	3	0	0	3.83
F.0-22.5	W24x55	35	19	4	0	0	3.83
F.0-23.5	W24x55	35	19	4	0	0	3.83
F.0-24.5	W24x55	35	19	4	0	0	3.83
H.2-19	W18x35	35	31	2	0	0	15.67
G.5-19	W18x35	35	31	3	0	0	15.67
G.5-20	W24x55	35	33	3	67.2	0	31.34
G.5-21	W24x55	35	35	3	67.2	0	31.34
G.5-22	W24x55	35	35	3	67.2	0	31.34
G.5-23	W24x55	35	35	3	67.2	0	31.34
G.5-24	W24x55	35	35	3	67.2	0	31.34
G.5-25	W18x40	35	26.8	3	0	0	31.34
G.6-25.9	W24x55	35	26.67	3	0	0	12
F.3-21.4	W14x22	35	17.5	2	0	0	23.33
F.3-21.7	W14x22	35	17.5	2	0	0	23.33

Type 1: The Girder suppc

Member	Member Size	Member Length (ft)	Member Z_x	Member b_f/2t_f	Member h/t_w	Member Height d	F_y (ksi)	Φ_b	Roof Screen Length l	Roof Screen Orientation to Girder
J.0-19.6	W24x55	24	134	6.94	54.6	23.6	50	0.9	0	None
J.0-20.5	W24x55	31.34	134	6.94	54.6	23.6	50	0.9	0	None
J.0-21.5	W24x55	31.34	134	6.94	54.6	23.6	50	0.9	0	None
J.0-22.5	W24x55	31.34	134	6.94	54.6	23.6	50	0.9	0	None
J.0-23.5	W24x55	31.34	134	6.94	54.6	23.6	50	0.9	0	None
J.0-24.5	W24x55	31.34	134	6.94	54.6	23.6	50	0.9	0	None
J.0-25.5	W24x94	31.34	254	5.18	41.9	24.3	50	0.9	0	None
J.0-26.2	W24x94	18	254	5.18	41.9	24.3	50	0.9	0	None
H.6-20.5	W18x35	31.34	66.5	7.06	53.5	17.7	50	0.9	4	Parallel
H.6-21.5	W18x35	31.34	66.5	7.06	53.5	17.7	50	0.9	4	Parallel
H.6-22.5	W18x35	31.34	66.5	7.06	53.5	17.7	50	0.9	4	Parallel
H.6-23.5	W18x35	31.34	66.5	7.06	53.5	17.7	50	0.9	4	Parallel
F.3-22.5	W18X35	31.34	66.5	7.06	53.5	17.7	50	0.9	4	Parallel
F.3-23.5	W18X35	31.34	66.5	7.06	53.5	17.7	50	0.9	4	Parallel
F.3-24.5	W18X35	31.34	66.5	7.06	53.5	17.7	50	0.9	4	Parallel
F.0-19.5	W24x55	31.34	134	6.94	54.6	23.6	50	0.9	0	None
F.0-21.5	W24x55	31.34	134	6.94	54.6	23.6	50	0.9	0	None
F.0-22.5	W24x55	31.34	134	6.94	54.6	23.6	50	0.9	0	None
F.0-23.5	W24x55	31.34	134	6.94	54.6	23.6	50	0.9	0	None
F.0-24.5	W24x55	28.26	134	6.94	54.6	23.6	50	0.9	0	None
H.2-19	W18x35	9	66.5	7.06	53.5	17.7	50	0.9	0	None
G.5-19	W18x35	22.67	66.5	7.06	53.5	17.7	50	0.9	0	None
G.5-20	W24x55	22.67	134	6.94	54.6	23.6	50	0.9	0	None
G.5-21	W24x55	22.67	134	6.94	54.6	23.6	50	0.9	0	None
G.5-22	W24x55	22.67	134	6.94	54.6	23.6	50	0.9	0	None
G.5-23	W24x55	22.67	134	6.94	54.6	23.6	50	0.9	0	None
G.5-24	W24x55	22.67	134	6.94	54.6	23.6	50	0.9	0	None
G.5-25	W18x40	22.67	78.4	5.73	50.9	17.9	50	0.9	0	None
G.6-25.9	W24x55	27.5	134	6.94	54.6	23.6	50	0.9	0	None
F.3-21.4	W14x22	15.33	33.2	7.46	53.3	13.7	50	0.9	0	None
F.3-21.7	W14x22	15.33	33.2	7.46	53.3	13.7	50	0.9	0	None

Type 1: The Girder suppc							
Member	Member Size	Distributed Live Load (lb/ft)	Distributed Nominal Beam Weight	ΦM_p	Dead Load (lb/ft)	Roof Screen Dead Load	Load Combination W_u (lb/ft)
J.0-19.6	W24x55	134.05	2.38	502.5	375.76	0	665
J.0-20.5	W24x55	134.05	2.43	502.5	375.95	0	666
J.0-21.5	W24x55	134.05	2.43	502.5	375.95	0	666
J.0-22.5	W24x55	134.05	2.43	502.5	375.95	0	666
J.0-23.5	W24x55	134.05	2.43	502.5	375.95	0	666
J.0-24.5	W24x55	134.05	0.78	502.5	369.67	0	658
J.0-25.5	W24x94	134.05	2.43	952.5	414.95	0	712
J.0-26.2	W24x94	134.05	2.11	952.5	413.75	0	711
H.6-20.5	W18x35	268.45	1.85	249.375	673.34	293.3424	1238
H.6-21.5	W18x35	268.45	1.85	249.375	673.34	293.3424	1238
H.6-22.5	W18x35	268.45	1.85	249.375	673.34	293.3424	1238
H.6-23.5	W18x35	268.45	1.85	249.375	673.34	293.3424	1238
F.3-22.5	W18X35	268.45	1.85	249.375	673.34	293.3424	1238
F.3-23.5	W18X35	268.45	1.85	249.375	673.34	293.3424	1238
F.3-24.5	W18X35	268.45	2.20	249.375	675.98	293.3424	1241
F.0-19.5	W24x55	134.05	2.43	502.5	375.95	0	666
F.0-21.5	W24x55	134.05	2.11	502.5	374.73	0	664
F.0-22.5	W24x55	134.05	2.43	502.5	375.95	0	666
F.0-23.5	W24x55	134.05	2.43	502.5	375.95	0	666
F.0-24.5	W24x55	134.05	2.69	502.5	376.97	0	667
H.2-19	W18x35	548.45	6.89	249.375	1418.10	0	2579
G.5-19	W18x35	548.45	4.10	249.375	1374.43	0	2527
G.5-20	W24x55	1096.9	4.37	502.5	4848.20	0	7573
G.5-21	W24x55	1096.9	4.63	502.5	4856.50	0	7583
G.5-22	W24x55	1096.9	4.63	502.5	4856.50	0	7583
G.5-23	W24x55	1096.9	4.63	502.5	4856.50	0	7583
G.5-24	W24x55	1096.9	4.63	502.5	4856.50	0	7583
G.5-25	W18x40	1096.9	3.55	294	2701.44	0	4997
G.6-25.9	W24x55	420	2.91	502.5	1066.41	0	1952
F.3-21.4	W14x22	816.55	2.28	124.5	1973.74	0	3675
F.3-21.7	W14x22	816.55	2.28	124.5	1973.74	0	3675

Type 1: The Girder suppc								
Member	Member Size	Roof Screen Design Moment	Other Load Design Moment	Total Design Moment M_u ft-kps	ΦM_p/M_u	Required Z_x (in^3)	Adequate Z_x?	b_f/2t_f≤9.2?
J.0-19.6	W24x55	0.000	32	32	15.73	8.5	yes	yes
J.0-20.5	W24x55	0.000	54	54	9.22	14.5	yes	yes
J.0-21.5	W24x55	0.000	54	54	9.22	14.5	yes	yes
J.0-22.5	W24x55	0.000	54	54	9.22	14.5	yes	yes
J.0-23.5	W24x55	0.000	54	54	9.22	14.5	yes	yes
J.0-24.5	W24x55	0.000	54	54	9.33	14.4	yes	yes
J.0-25.5	W24x94	0.000	58	58	16.33	15.5	yes	yes
J.0-26.2	W24x94	0.000	19	19	49.62	5.1	yes	yes
H.6-20.5	W18x35	1.966	101	103	2.42	27.5	yes	yes
H.6-21.5	W18x35	1.966	101	103	2.42	27.5	yes	yes
H.6-22.5	W18x35	1.966	101	103	2.42	27.5	yes	yes
H.6-23.5	W18x35	1.966	101	103	2.42	27.5	yes	yes
F.3-22.5	W18X35	1.966	101	103	2.42	27.5	yes	yes
F.3-23.5	W18X35	1.966	101	103	2.42	27.5	yes	yes
F.3-24.5	W18X35	1.966	102	104	2.41	27.6	yes	yes
F.0-19.5	W24x55	0.000	54	54	9.22	14.5	yes	yes
F.0-21.5	W24x55	0.000	54	54	9.24	14.5	yes	yes
F.0-22.5	W24x55	0.000	54	54	9.22	14.5	yes	yes
F.0-23.5	W24x55	0.000	54	54	9.22	14.5	yes	yes
F.0-24.5	W24x55	0.000	44	44	11.32	11.8	yes	yes
H.2-19	W18x35	0.000	17	17	14.32	4.6	yes	yes
G.5-19	W18x35	0.000	108	108	2.30	28.9	yes	yes
G.5-20	W24x55	0.000	324	324	1.55	86.5	yes	yes
G.5-21	W24x55	0.000	325	325	1.55	86.6	yes	yes
G.5-22	W24x55	0.000	325	325	1.55	86.6	yes	yes
G.5-23	W24x55	0.000	325	325	1.55	86.6	yes	yes
G.5-24	W24x55	0.000	325	325	1.55	86.6	yes	yes
G.5-25	W18x40	0.000	214	214	1.37	57.1	yes	yes
G.6-25.9	W24x55	0.000	123	123	4.09	32.8	yes	yes
F.3-21.4	W14x22	0.000	72	72	1.73	19.2	yes	yes
F.3-21.7	W14x22	0.000	72	72	1.73	19.2	yes	yes

Type 1: The Girder suppc

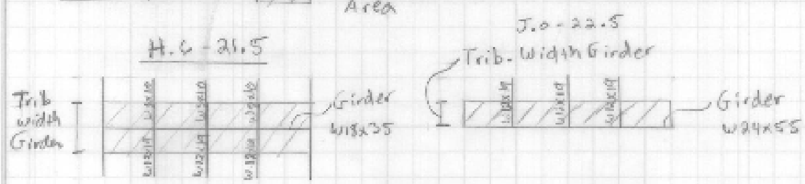
Member	Member Size	h/t_w≤90.5?	Use plastic capacity check?	ΦM_p> M_u?	Adequate beam size?
J.0-19.6	W24x55	yes	yes	yes	yes
J.0-20.5	W24x55	yes	yes	yes	yes
J.0-21.5	W24x55	yes	yes	yes	yes
J.0-22.5	W24x55	yes	yes	yes	yes
J.0-23.5	W24x55	yes	yes	yes	yes
J.0-24.5	W24x55	yes	yes	yes	yes
J.0-25.5	W24x94	yes	yes	yes	yes
J.0-26.2	W24x94	yes	yes	yes	yes
H.6-20.5	W18x35	yes	yes	yes	yes
H.6-21.5	W18x35	yes	yes	yes	yes
H.6-22.5	W18x35	yes	yes	yes	yes
H.6-23.5	W18x35	yes	yes	yes	yes
F.3-22.5	W18X35	yes	yes	yes	yes
F.3-23.5	W18X35	yes	yes	yes	yes
F.3-24.5	W18X35	yes	yes	yes	yes
F.0-19.5	W24x55	yes	yes	yes	yes
F.0-21.5	W24x55	yes	yes	yes	yes
F.0-22.5	W24x55	yes	yes	yes	yes
F.0-23.5	W24x55	yes	yes	yes	yes
F.0-24.5	W24x55	yes	yes	yes	yes
H.2-19	W18x35	yes	yes	yes	yes
G.5-19	W18x35	yes	yes	yes	yes
G.5-20	W24x55	yes	yes	yes	yes
G.5-21	W24x55	yes	yes	yes	yes
G.5-22	W24x55	yes	yes	yes	yes
G.5-23	W24x55	yes	yes	yes	yes
G.5-24	W24x55	yes	yes	yes	yes
G.5-25	W18x40	yes	yes	yes	yes
G.6-25.9	W24x55	yes	yes	yes	yes
F.3-21.4	W14x22	yes	yes	yes	yes
F.3-21.7	W14x22	yes	yes	yes	yes

APPENDIX F: Typical Type I Girder Calculation

Type 1 Girder Analysis

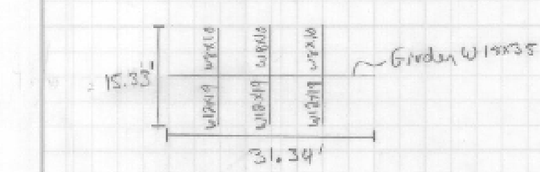
Type 1 Girders support Adjacent Steel beams throughout the entire tributary Area of the Girder

Examples: Tributary Area



In order to find the effect of the beams on the Girder we used a method of analysis where the we distributed the weight of the adjacent beams along the length of the girder

$$\frac{\left(\text{Average Nominal Weight of Adjacent beams}\right)}{\left(\text{Tributary width of Adj Beams}\right)}\left(\text{Trib. width of Girder}\right) = \left(\text{Distributed load } \frac{lb}{ft} \text{ Along Girder}\right)$$



Dead Load Calculation

Girder Weight = 35 lb/ft

Trib width = 7.67'

Concrete slab = 54.375 (7.67') = 417 lb/ft

steel decking = 2 (7.67') = 15.34 lb/ft

Type 1

Roofing Material = 15 (7.67) = 115 lb/ft

Suspended Services = 5 (7.67) = 38.35 lb/ft
Ceiling load = 5 (7.67) = 38.35 lb/ft

Average Nominal Adjacent Beam Weight = $\frac{19+10}{2}$ = 14.5 lb/ft

Effect of Adjacent Beams on Girder:

$$\frac{14.5 \text{ lb/ft}}{\text{Trib width} = 8'} (7.67') = 13.90 \text{ lb/ft}$$

Beams

DL = 35 + 417 + 15.34 + 115 + 38.35 + 38.35 + 13.90
DL = 672.94 lb/ft

LL = 35 (7.67) = 268.45 lb/ft

W_u = 1.4 (DL) = 924.12 lb/ft
or
1.2DL + 1.6 LL = 1238 lb/ft

Choose larger

Fixed End Connections

$$M = \frac{w_u L^2}{12} = \frac{1238 (31.34)^2}{12 / 1000} = 101.25 \text{ k ft}$$

$$M_{roofScreen} = \frac{(1.6)(5.85)(31.34)(4')^2}{12(31.34)^2} \left(6(31.34)^2 - 8(4)(31.34) + 3(4)^2 \right)$$

= 1.966 ft k

Type 1

$M_u = 101.25 + 1.966 = 103$ ftkips

$\phi M_p = 0.9(Z_x)(F_y)/12 = 0.9(66.5)(50)/12 = 249$ kft

$$\frac{249}{103} = 2.42 = \frac{\phi M_p}{M_u} \checkmark$$

Check Required Zx

$$\frac{(M_u \times 12)}{\phi F_y} = \frac{103 \times 12}{0.9(50)} = 27.5$$

$Z_x = 66.5 > 27.5$ $\boxed{OK}$

Plastic Capacity

$\frac{b_f}{2t_f} = 7.06 \leq 9.2$ $\boxed{OK}$

$\frac{h}{t_w} = 53.5 \leq 90.5$ $\boxed{OK}$

Use plastic check ✓

$\phi M_p > M_u$

$\boxed{\text{Beam Size is Adequate}}$

APPENDIX G: Type II Girder Calculations

Type 2: The Girder supports adjacent beams for half the girder's tributary area.										
Member	Member Size	Member Weight (lb/ft)	Weight Of Concrete Slab (lb/ft^2)	Weight of Steel Decking (lb/ft^2)	Roofing Material (lb/ft^2)	Suspended Services (lb/ft^2)	Ceiling Load (lb/ft^2)	Live Load (lb/ft^2)	Ave.Nominal Adjacent Beam	Number of Beam Tributary Widths
H.6-19.5	W16x31	31	54.375	2	15	5	5	35	19	4
H.6-24.5	W18x35	35	54.375	2	15	5	5	35	8.8	2.5
H.6-25.5	W18x35	35	54.375	2	15	5	5	35	19	4
H.6-26.2	W12x14	14	54.375	2	15	5	5	35	19	2
H.3-20.5	W18x35	35	54.375	2	15	5	5	35	10	4
H.3-21.5	W18x35	35	54.375	2	15	5	5	35	10	4
H.3-22.5	W18x35	35	54.375	2	15	5	5	35	10	4
H.3-23.5	W18x35	35	54.375	2	15	5	5	35	10	4
H.3-24.5	W18x35	35	54.375	2	15	5	5	35	10	2
F.6-20.5	W18x35	35	54.375	2	15	5	5	35	10	4
F.6-21.5	W18x35	35	54.375	2	15	5	5	35	22	3
F.6-22.5	W18x35	35	54.375	2	15	5	5	35	10	4
F.6-23.5	W18x35	35	54.375	2	15	5	5	35	10	4
F.6-24.5	W18x35	35	54.375	2	15	5	5	35	10	2
F.3-19.5	W16x31	31	54.375	2	15	5	5	35	19	4
F.3-20.5	W18x35	35	54.375	2	15	5	5	35	10	4

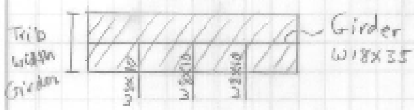
APPENDIX H: Typical Type II Girder Calculations

Type 2 Girder Analysis

Type 2 Girders support Adjacent Steel beams through only half the tributary Area of the Girder

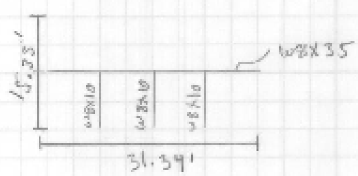
examples: Tributary Area

H.3-22.5



The effect of the Beams on the Girder is only half of the effect on a Type 1 Girder because Adjacent Beams support only half of the tributary Area. Therefore, the nominal beam weight is only multiplied by half the beams tributary width when calculating dead load of steel

$$\frac{\left(\text{Average Nominal Weight of Adjacent Beams}\right)}{\left(\text{Tributary widths of Adj. Beams}\right)} \times \frac{\left(\text{Trib. width Girder}\right)}{2} = \left(\text{Distributed load Along Girder}\right)$$



Type 2

Dead Load Calculation

Girder weight = 35 lb/ft

Trib width = 7.67

Concrete Slab = 54.375 (7.67') = 417 lb/ft

Steel Decking = 2(7.67') = 15.34 lb/ft

Roofing Material = 15(7.67) = 115 lb/ft

Suspended Services = 5(7.67) = 38.35 lb/ft

Ceiling load = 5(7.67) = 38.35 lb/ft

Average Nominal Adjacent Beam weight = 10 lb/ft

Effect of Adjacent Beams on: Girder

$$\frac{10 \text{ lb/ft}}{8'}(7.67') = 9.59 \text{ lb/ft}$$

Trib width Beams

Mechanical Unit load = 67.2 (7.67) = 515.4

DL

DL = 35 + 417 + 15.34 + 115 + 38.35 + 38.35 + 9.59 + 515.4

DL = 1179 lb/ft

LL = 35 (7.67) = 268.43 lb/ft

W_u = 1.4 DL = 1651 lb/ft

or

1.2DL + 1.6LL = 1845 lb/ft

Choose larger

Type 2

Fixed end connections (No Roof screen Load)

$$M_u = \frac{W_u L^2}{12} = \frac{(1845)(31.34)^2}{12 \cancel{/1000}} = 151 \text{ ft kips}$$

$$\phi M_p = 0.9(Z_x)(F_y)/12 = 0.9(66.5)(50)/12 = 249$$

$$\frac{249}{151} = 1.65 = \frac{\phi M_p}{M_u} \checkmark$$

Check Required Z_x

$$\frac{M_u \times 12}{\phi F_y} = \frac{151 \times 12}{0.9 \times 50} = 40.27$$

$$Z_x = 66.5 > 40.27 \boxed{OK}$$

Plastic Capacity

$$\frac{b_f}{2t_f} = 7.06 \le 9.2 \boxed{OK}$$

$$\frac{h}{t_w} = 53.5 \le 90.5 \boxed{OK}$$

Use plastic check

$\phi M_p > M_u$

$\boxed{\text{Beam size is Adequate}}$

APPENDIX I: Type III Girder Calculations

Type 3: Giders that Support Girders

Member	Member Size	Member Weight (lb/ft)	Weight Of Concrete Slab (lb/ft^2)	Weight of Steel Decking (lb/ft^2)	Weight of adjacent Beams and Girders	Roofing Material (lb/ft^2)	Suspended Services (lb/ft^2)	Ceiling Load (lb/ft^2)	Live Load (lb/ft^2)
H.6-19	W16x26	26	54.375	2	82.07	15	5	5	35
H.5-20	W24x55	55	54.375	2	162.26	15	5	5	35
H.5-21	W24x55	55	54.375	2	179.13	15	5	5	35
H.5-22	W24x55	55	54.375	2	179.13	15	5	5	35
H.5-23	W24x55	55	54.375	2	179.13	15	5	5	35
H.5-24	W24x55	55	54.375	2	168.92	15	5	5	35
H.5-25	W21x44	44	54.375	2	160.17	15	5	5	35
H.5-26	W18x35	35	54.375	2	106.73	15	5	5	35
H.6-26.4	W16x26	26	54.375	2	15.56	15	5	5	35
F.5-19	W18x35	35	54.375	2	72.63	15	5	5	35
F.5-20	W24x55	55	54.375	2	149.02	15	5	5	35
F.5-21	W24x55	55	54.375	2	159.89	15	5	5	35
F.5-22	W24x55	55	54.375	2	167.16	15	5	5	35
F.5-23	W24x55	55	54.375	2	181.2	15	5	5	35
F.5-24	W24x55	55	54.375	2	180.24	15	5	5	35
F.5-25	W16x31	31	54.375	2	92.49	15	5	5	35

Type 3: Giders that Support Girders

Member	Member Size	Dist. Mechanical Unit Load (lb/ft^2)	Roof Screen Load (lb/ft^2)	T_w (ft) Girder	Member Length	Member Z_x	Member b_f/2t_f	Member h/t_w	Member Height d	F_y (ksi)	Φ_b	Roof Screen	Roof Screen Orientation to
H.6-19	W16x26	0	0	15.67	14	44.2	7.97	56.8	15.7	50	0.9	0	None
H.5-20	W24x55	67.2	5.85	31.34	23	134	6.94	54.6	23.6	50	0.9	3	Parallel
H.5-21	W24x55	67.2	5.85	31.34	23	134	6.94	54.6	23.6	50	0.9	5	Perpendicular
H.5-22	W24x55	67.2	5.85	31.34	23	134	6.94	54.6	23.6	50	0.9	5	Perpendicular
H.5-23	W24x55	67.2	5.85	31.34	23	134	6.94	54.6	23.6	50	0.9	5	Perpendicular
H.5-24	W24x55	67.2	5.85	31.34	23	134	6.94	54.6	23.6	50	0.9	5	Perpendicular
H.5-25	W21x44	0	0	31.34	23	95.4	7.22	53.6	20.7	50	0.9	0	None
H.5-26	W18x35	0	0	31.34	23	66.5	7.06	53.5	17.7	50	0.9	0	None
H.6-26.4	W16x26	0	0	7	24.2	44.2	7.97	56.8	15.7	50	0.9	0	None
F.5-19	W18x35	0	0	15.67	23	66.5	7.06	53.5	17.7	50	0.9	0	None
F.5-20	W24x55	67.2	5.85	31.34	23	134	6.94	54.6	23.6	50	0.9	3	Parallel
F.5-21	W24x55	67.2	5.85	31.34	23	134	6.94	54.6	23.6	50	0.9	5	Perpendicular
F.5-22	W24x55	67.2	5.85	31.34	23	134	6.94	54.6	23.6	50	0.9	5	Perpendicular
F.5-23	W24x55	67.2	5.85	31.34	23	134	6.94	54.6	23.6	50	0.9	5	Perpendicular
F.5-24	W24x55	67.2	5.85	31.34	23	134	6.94	54.6	23.6	50	0.9	5	Perpendicular
F.5-25	W16x31	0	0	27.23	23	54	6.28	51.6	15.9	50	0.9	0	None

Type 3: Giders that Support Girders

Member	Member Size	Distributed Live Load (lb/ft)	ΦM_p	Dead Load (lb/ft)	Roof Screen Dead Load	Load Combination	Roof Screen Design Moment	Other Load Design Moment	Total Design Moment M_u ft-kps	ΦM_p/M_u
H.6-19	W16x26	548.45	165.75	1383.22	0.00	2537.38	0.00	41.44	41.44	4.00
H.5-20	W24x55	1096.90	502.50	5056.94	215.28	7823.37	0.81	344.88	345.69	1.45
H.5-21	W24x55	1096.90	502.50	5073.81	293.34	7843.61	2.69	345.77	348.46	1.44
H.5-22	W24x55	1096.90	502.50	5073.81	293.34	7843.61	2.69	345.77	348.46	1.44
H.5-23	W24x55	1096.90	502.50	5073.81	293.34	7843.61	2.69	345.77	348.46	1.44
H.5-24	W24x55	1096.90	502.50	5063.60	293.34	7831.36	2.69	345.23	347.92	1.44
H.5-25	W21x44	1096.90	357.75	2754.46	0.00	5060.40	0.00	223.08	223.08	1.60
H.5-26	W18x35	1096.90	249.38	2692.02	0.00	4985.47	0.00	219.78	219.78	1.13
H.6-26.4	W16x26	245.00	165.75	611.19	0.00	1125.42	0.00	54.92	54.92	3.02
F.5-19	W18x35	548.45	249.38	1382.78	0.00	2536.85	0.00	111.83	111.83	2.23
F.5-20	W24x55	1096.90	502.50	5043.70	215.28	7807.48	0.81	344.18	344.99	1.46
F.5-21	W24x55	1096.90	502.50	5054.57	293.34	7820.52	2.69	344.75	347.45	1.45
F.5-22	W24x55	1096.90	502.50	5061.84	293.34	7829.25	2.69	345.14	347.83	1.44
F.5-23	W24x55	1096.90	502.50	5075.88	293.34	7846.10	2.69	345.88	348.57	1.44
F.5-24	W24x55	1096.90	502.50	5074.92	293.34	7844.94	2.69	345.83	348.52	1.44
F.5-25	W16x31	953.05	202.50	2339.33	0.00	4332.08	0.00	190.97	190.97	1.06

Type 3: Giders that Support Girders

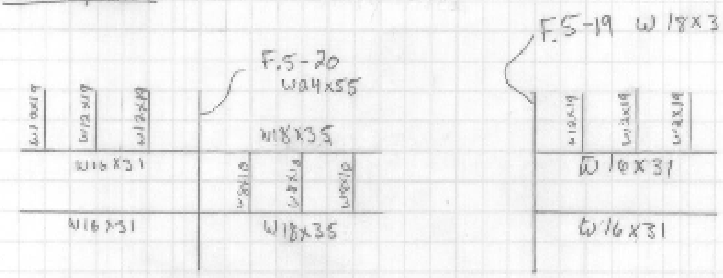
Member	Member Size	Required Z_x (in^3)	Adequate Z_x?	b_f/2t_f≤9.2?	h/t_w≤90.5 ?	Use plastic capacity	ΦM_p> M_u?	Adequate beam size?
H.6-19	W16x26	11.05	yes	yes	yes	yes	yes	yes
H.5-20	W24x55	92.18	yes	yes	yes	yes	yes	yes
H.5-21	W24x55	92.92	yes	yes	yes	yes	yes	yes
H.5-22	W24x55	92.92	yes	yes	yes	yes	yes	yes
H.5-23	W24x55	92.92	yes	yes	yes	yes	yes	yes
H.5-24	W24x55	92.78	yes	yes	yes	yes	yes	yes
H.5-25	W21x44	59.49	yes	yes	yes	yes	yes	yes
H.5-26	W18x35	58.61	yes	yes	yes	yes	yes	yes
H.6-26.4	W16x26	14.65	yes	yes	yes	yes	yes	yes
F.5-19	W18x35	29.82	yes	yes	yes	yes	yes	yes
F.5-20	W24x55	92.00	yes	yes	yes	yes	yes	yes
F.5-21	W24x55	92.65	yes	yes	yes	yes	yes	yes
F.5-22	W24x55	92.75	yes	yes	yes	yes	yes	yes
F.5-23	W24x55	92.95	yes	yes	yes	yes	yes	yes
F.5-24	W24x55	92.94	yes	yes	yes	yes	yes	yes
F.5-25	W16x31	50.93	yes	yes	yes	yes	yes	yes

APPENDIX J: Typical Type III Girder Calculations

Type 3 Girders

Type 3 Girders are Girders that Support other Girders and their adjacent beam loads

examples:



Due to the inconsistent nature of the Type 3 Girders, Developing a universal method for determining the weight of the adjacent Steel proved to be impractical. As a result each Type 3 Girder's Adjacent Beam & Girder Loads were calculated individually and these values were incorporated into the dead Load Calculation for the Type 3 Girder. An analysis follows that Mirrors that of the Type 1 Girder.

F.5-20

Dead Load Calculation

Type 3 Girder Weight = 55 lb/ft

Trib width = 31.34'

Concrete Slab = 54.375 (31.34) = 1704.11 lb/ft

Steel decking = 2(31.34) = 62.68 lb/ft

Roofing Material = 15(31.34) = 470.1 lb/ft

Suspended Services = 5(31.34) = 156.7 lb/ft

Type 3

Ceiling Load = 5(31.34) = 156.7 lb/ft

Weight of adjacent beams & Girders = 149.02 lb/ft

(See Type 3 Girder Calculations for Detail on beam & Girder weight Calculation)

Mechanical Unit Load = 67.2(31.34) = 2106 lb/ft

$DL = 55 + 31.34 + 1704 + 62.68 + 470.1 + 156.7 + 156.7 + 149.02 + 2106$

$DL = 5644$

$LL = 35(31.34) = 1097$

$w_u = 1.4\,DL = 7061.6$ lb/ft

or

$1.2DL + 1.6LL = \boxed{7807}$ lb/ft

choose larger

Fixed end Connections

$$M = \frac{w_u L^2}{12} = \frac{(7807)(23')^2}{12} = 344.18$$

$$M_{roofScreen} = \frac{(1.6)(5.85)(23)(3')^2}{12(23)^2}\left(6(23')^2 - 8(3')(23) + 3(3')^2\right)$$

$= .81$ ftk

Type 3

$M_u = 344.18 + .81 = 345$ ftk

$\phi M_p = 0.9(Z_x)(F_y)/12 = 0.9(134)(50)/12 = 502.5$

$\frac{502.5}{345} = 1.46 = \frac{\phi M_p}{M_u}$ ✓

Check Required Z_x

$\frac{(M_u)(12)}{\phi F_y} = \frac{(345)(12)}{(0.9)(50)} = 92$

$Z_x = 134 > 92$ $\boxed{OK}$

Plastic Capacity

$\frac{b_f}{2t_f} = 6.94 \leq 9.2$ $\boxed{OK}$

$\frac{h}{t_w} = 54.6 \leq 90.5$ $\boxed{OK}$

Use Plastic Check

$\phi M_p > M_u$

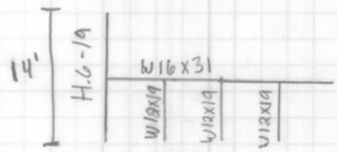
$\boxed{\text{Beam Size is Adequate}}$

APPENDIX K: Type III Adjacent Member Dead Load Calculation

Type 3 Girders

H.6 – 19 W16x26

Deadload effect of adjacent Members on Type 3 Girder



General Equation:

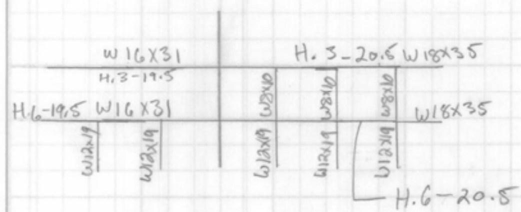
$$\left(\frac{\text{Nominal Adjacent Beam Weight}}{\text{Tributary width of Adj Beam}}\right)\left(\text{Trib. width of Girder for steel}\right) = \left(\text{Distributed Load Along Girder}\right)$$

$$\frac{19\ \text{lb/ft}}{8'}\left(3.83\right) = 9.10\ \text{lb/ft}$$

$$\frac{9.17+31}{7.67}\left(75.67\right) = \boxed{82.07\ \text{lb/ft Dead Load Steel}}$$

Type 3 Girders

H.5-20 W24X55



H.6-20.5 Average

$$\frac{13.5 \text{ lbs/ft}}{8'} \times 7.667' = 12.93 \text{ lb/ft}$$

H.3-20.5

$$\frac{10 \text{ lb/ft}}{8'} \times 3.83' = 4.79 \text{ lb/ft}$$

H.3-19.5 = 31 lb/ft

H.6-19.5

$$\frac{19 \text{ lb/ft}}{8'} \times 3.83' = 9.10 \text{ lb/ft}$$

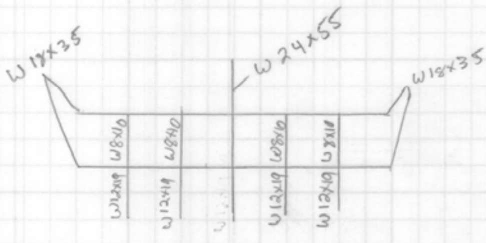
Nominal weights of Adjacent Girders/beams adjacent to Type 3

$$\frac{\underbrace{(12.93 \text{ lb/ft} + 4.79 + 9.10)}_{\text{weight of steel on Girders Adjacent to type 3 girder}} + (35 + 35 + 31 + 31)}{4} = 39.71$$

$$\frac{39.71}{7.67}(31.34) = \boxed{162.26 \text{ lb/ft on Girder H.6-20}}$$

Type 3 Girders

H.5 - 21   W 24x55
H.5 - 22   W 24x55
H.5 - 23   W 24x55



$$\frac{13.5 \text{ lb/ft}}{8'} \times 7.667' = 12.93 \text{ lb/ft}$$

$$\frac{10 \text{ lb/ft}}{8'} \times 3.83' = 4.79 \text{ lb/ft}$$

Nom Adj. Beam Wts.

$$\frac{2(12.92 + 4.76) + 4(35)}{4} = 43.84 \text{ lb/ft}$$

Average Adjacent Girder weight on Main girder

Trib width girder (Type 3)

$$\frac{(43.84) \text{ lb/ft}}{7.67'} (31.34') = \boxed{179.13 \text{ lb/ft}}$$

Dead load of Steel on Type 3 Girder

Type 3 Girders

H.5-24

H.6-23.5 $\dfrac{13.5 \text{ lb/ft}}{8} \times 7.67 = 12.93 \text{ lb/ft}$

H.3-23.5 $\dfrac{10 \text{ lb/ft}}{8'} \times 3.83 = 4.79 \text{ lb/ft}$

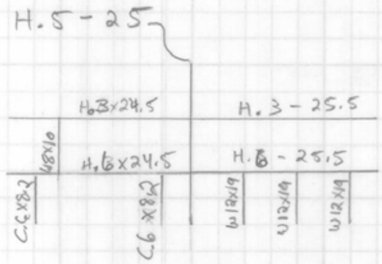
H.3-24.5 $\dfrac{10 \text{ lb/ft}}{31.34'} \times 3.83 = 1.22 \text{ lb/ft}$

H.6-24.5 $\dfrac{8.8 \text{ lb/ft}}{10.45} \times 7.67 = 6.46 \text{ lb/ft}$

$$\frac{(12.93 + 4.79 + 1.22 + 6.46) + 4(35)}{4} = 41.34$$

$$\frac{41.34 \text{ lb/ft}}{7.67} \times (31.34) = \boxed{168.92 \text{ lb/ft}}$$

Type 3 Girders



H.6 - 24.5

$$\frac{8.8 \text{ lb/ft}}{10.45} \times 7.67 = 6.46 \text{ lb/ft}$$

H.3 - 24.5

$$\frac{10 \text{ lb/ft}}{31.34'} \times 3.83' = 1.22 \text{ lb/ft}$$

H.3 - 25.5

$$0 \text{ lb/ft}$$

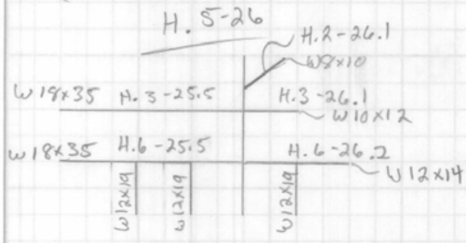
H.6 - 25.5

$$\frac{19 \text{ lb/ft}}{8'} \times 3.83' = 9.10 \text{ lb/ft}$$

$$\frac{(6.46 + 1.22 + 0 + 9.10) + 4(35)}{4} = 39.20 \text{ lb/ft}$$

$$\frac{39.20 \text{ lb/ft}}{7.67} \times 31.34 = \boxed{160.17 \text{ lb/ft}}$$

Type 3 Girders



H.3-25.5 $\quad 0$

H.6-25.5 $\quad \dfrac{19 \text{ lb/ft}}{8'} \times 3.83 = 9.10 \text{ lb/ft}$

H.2-26.1 $\quad 0$

H.3-26.1 $\quad 0$

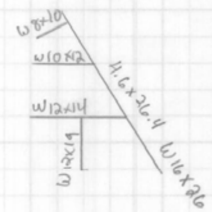
H.6-26.2 $\quad \dfrac{19}{8'} \times (6.38') = 15.15 \text{ lb/ft}$

$$\frac{(9.10 + 15.5) + (10 + 12 + 14 + 35(2))}{5} = 26.12$$

$$\frac{26.12 \text{ lb/ft}}{7.67}(31.34) = \boxed{106.73 \text{ lb/ft}}$$

Type 3 Girders

H.6 - 26.4



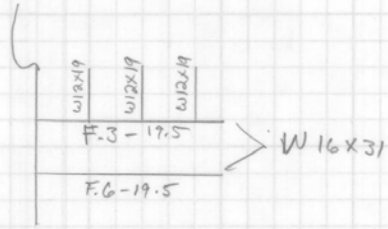
$$\frac{19}{8}(6.38) = 15.15 \text{ lb/ft}$$

$$\frac{(15.15) + (10+12+14)}{3} = 17.05 \text{ lb/ft}$$

$$\frac{17.05 \text{ lb/ft}}{7.67}(7.00) = \boxed{15.56 \text{ lb/ft}}$$

Type 3 Girders

F. 5 - 19



F. 3 - 19.5

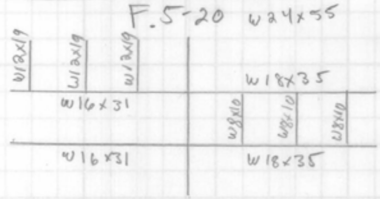
$$\frac{19\ \text{lb/ft}}{8'}(3.83)' = 9.10\ \text{lb/ft}$$

$$\frac{(9.10) + 2(31)}{2} = 35.55\ \text{lb/ft}$$

$$\frac{35.55}{7.67}(15.67) = \boxed{72.63\ \text{lb/ft}}$$

Type 3 Girders

F.5-20 W24x55



$$\frac{19\ lb/ft}{8'}(3.83) = 9.10\ lb/ft$$

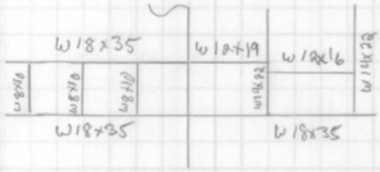
$$\frac{10}{8'}(3.83) = 4.79\ lb/ft$$

$$\frac{(9.10 + 4.79) + 2(31) + 2(35)}{4} = 36.47\ lb/ft$$

$$\frac{36.47\ lb/ft}{7.67}(31.34) = \boxed{149.02\ lb/ft}$$

Type 3 Girders

F.5-21 W24x55



$$\frac{10}{8'}(3.83) = 4.79 \text{ lb/ft}$$

$$\frac{17.5}{(7.67)}(12.57) = 28.5 \text{ lb/ft}$$

$$\frac{28.5}{10.44} \times (7.67) = 20.94 \text{ lb/ft}$$

$$\frac{((2)4.79 + 20.94) + (19 + 35(3))}{4} = 39.13$$

$$\frac{39.13}{7.67}(31.34) = \boxed{159.89 \text{ lb/ft}}$$

Type 3 Girders

F.5-22

$$\frac{28.5}{10.44} \times (7.67) = 20.94 \text{ lb/ft}$$

$$\frac{14.5}{8} (7.67) = 13.90 \text{ lb/ft}$$

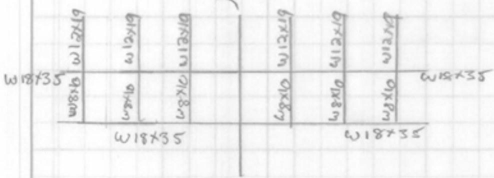
$$\frac{10}{8} (3.83) = 4.79 \text{ lb/ft}$$

$$\frac{(20.94 + 4.79 + 13.90) + (3(35) + 19)}{4} = 40.91 \text{ lb/ft}$$

$$\frac{40.91 \text{ lb/ft}}{7.67} (31.34) = \boxed{167.16 \text{ lb/ft}}$$

Type 3 Girders

F.5-23



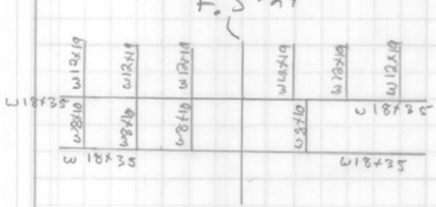
$$\frac{14.5}{8}(7.67) = 13.90 \text{ lb/ft}$$

$$\frac{10}{8}(3.83) = 4.79 \text{ lb/ft}$$

$$\frac{\left(13.90(2) + 4.79(2)\right) + \left(35(4)\right)}{4} = 44.35 \text{ lb/ft}$$

$$\frac{44.35}{7.67}(31.34) = \boxed{181.20 \text{ lb/ft}}$$

Type 3 Girders



$$\frac{14.5}{8}(7.67) = 13.90 \text{ lb/ft}$$

$$\frac{10}{8}(3.83) = 4.79 \text{ lb/ft}$$

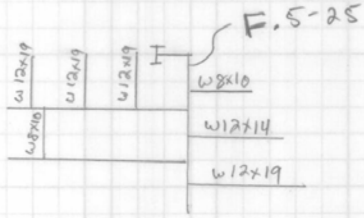
$$\frac{16.76}{10}(7.67) = 12.85 \text{ lb/ft}$$

$$\frac{10}{(15.67)}(7.67) = 4.89 \text{ lb/ft}$$

$$\frac{(13.90 + 4.79 + 12.85 + 4.89) + 35(4)}{4} = 44.11 \text{ lb/ft}$$

$$\frac{44.11}{(7.67)}(31.34) = 180.24$$

Type 3 Girders



$$\frac{16.76}{10}(7.67) = 12.85 \text{ lb/ft}$$

$$\frac{10}{15.67}(7.67) = 4.89 \text{ lb/ft}$$

$$\frac{(12.85 + 4.89) + (2(35) + 10 + 14 + 19)}{5} = 130.79$$

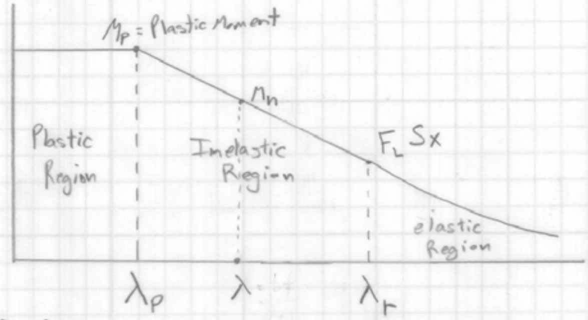
$$\frac{26.15}{7.67} \qquad \left(\frac{7.32 + 11.37 + 15.41}{3} + 15.76\right) = \boxed{92.49 \text{ lb/ft}}$$

APPENDIX L: Moment Capacity for Members with Non-compact Sections

1

For Beams that Fail $b_f/2t_f \leq 9.2$

Use inelastic check: Sample Calculation



H.5-20.2 W 8x10

$F_r = 10$

$F_L = (F_y - F_r) = (50 - 10) = 40$

$S_x = 7.81$ (For W 8x10)

$F_L S_x = 40(7.81) = 312.4$

$\lambda_p = 9.2$

$\lambda_r = 90.5$

$\lambda = \dfrac{b_f}{2t_f} = 9.61$

Find M_n

Interpolate between λ between λ_p & λ_r to determine M_n between M_p & $F_L S_x$

②

Inelastic Check (continued)

$$M_p - \left[\left(\frac{\frac{b_f}{2t_f} - \lambda_p}{\lambda_r - \lambda_p}\right)(M_p - F_L S_x)\right] = M_n$$

$$M_p - \left(\frac{9.61 - 9.2}{90.5 - 9.2}\right)(36.96 - .31) = 36.8$$

$$\phi M_n = 36.8(.9) = 33.12 > 19.1 = M_u \quad \boxed{OK}$$

$$\frac{\phi M_n}{M_u} = \frac{33.12}{19.1} = \boxed{1.733 \checkmark}$$

Repeat Procedure For each beam that Fails the Plastic Moment Capacity test $\frac{b_f}{2t_f} \leq 9.2$

APPENDIX M: Mechanical System Loads

60 Prescott Street
Roof Mechanical Systems

Unit No	Manufacturer	Model & Size	Weight (lbs)	Design Area	Measured Area
RTU-4	MCQUAY	RDT045C	12,065		570
MAU-1	MCQUAY	OAH090GDAC	20,943		363
MAU-2	MCQUAY	OAH090GDAC	20,943		373.9
SCHWP-1	BELL & GOSSETT	Series 1510, 4BC	1000		3.1
SCHWP-2	BELL & GOSSETT	Series 1510, 4BC	1000		3.1
GHRP-1	BELL & GOSSETT	Series 80, 4x4x11	1000	26"x16-1/8"	
GHRP-2	BELL & GOSSETT	Series 80, 3x3x9-1/28	1000	23"x14-1/8"	9.7
EF-6	GREENHECK	CUBE-200HP	127	30"x30"	5.4
Lab Exhaust System	STROBIC		45,300	20'1"x25'	520
CH-1	YORK	YCAV0247SA46	14,680	96"x318 3/8"	168.6
CH-2	YORK	YCAV0247SA46	14,680	96"x318 3/8"	168.6
PCHWP-1	BELL & GOSSETT	Series 80, 5x5x7	1000	12"x13"	5.32
PCHWP-2	BELL & GOSSETT	Series 80, 5x5x7	1000	12"x13"	5.32

APPENDIX N: Mechanical System/Roof Screen Distributed Load

Calculation Mechanical Units Load

Combined weight of mech. units = 134,738 lbs

Total footprint of mech. units = 2005 SF

distributed load of mech. units = 67.2 lbs/SF

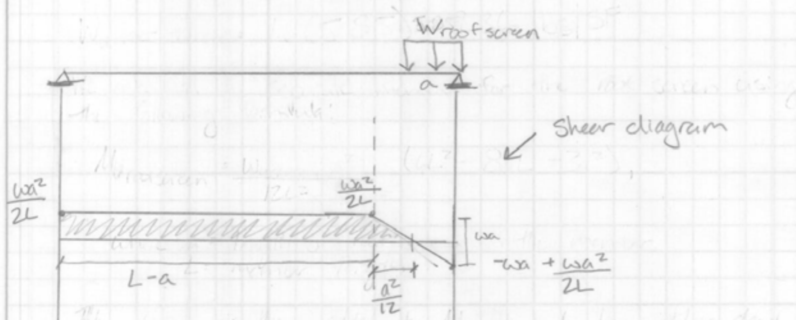
This load of 67.2 lbs/SF is applied over the length of all members that are supporting any part of a mech. unit

Calculation of Roof Screen Load

Total weight of roof screen = 10,005 lbs

Total footprint of roof screen = 1710 SF

distributed load of roof screen = 5.85 lbs/SF



$$\frac{wa}{a} = \frac{\frac{wa^2}{2L}}{x}, \quad x = \frac{a^2}{12}$$

$M_{max\,roof\,screen}$ = Σ area under shear diagram

$$M_{max\,r.s} = \frac{wa^2}{2L}(L-a) + \frac{1}{2}\left(\frac{wa^2}{2L}\right)\left(\frac{a^2}{12}\right)$$

$$\boxed{M_{max\,roof\,screen} = \frac{wa^2}{2} - \frac{wa^3}{2L} + \frac{wa^4}{48L}}$$

For each member, $M_u + M_{u\,max\,roof\,screen} = M_{u\,max}$ (design moment)

APPENDIX O: Purposes of Mechanical Systems

McQuay RDT045C:
McQuay RoofPak Unit

- Outdoor Air Handler
- Singlezone Unit
- Draw through cooling coil
- Cooling capacity of 45 Nominal tons
- 18,000 CFM

McQuay OAH090GDAC:
McQuay Skyline Outdoor Air Hander

- Outdoor Air Handler
- 90 nominal square foot of coil
- Draw-through cooling coil location
- Motor along side of fan housing
- Standard unit cross section
- 45,000 CFM

http://www.mcquay.com/McQuay/ProductInformation/AirHandlerOutdoor/AirHandlerOutdoor

Bell and Gossett Series 1510, 4BC:

- Used for hydronic heating and cooling services and other general uses
- Centrifugal pump
- Base-mounted
- End-suction
- 4000 GPM/ 570GPM
- Head: 92 ft

http://www.bellgossett.com/productPages/Parts-Series-1510.asp

Bell and Gossett Series 80:

- Used for hydronic heating and cooling services and other general uses
- Centrifugal pump
- Close-coupled in-line mounted pump
- 2500 GPM/210 GPM
- Head: 45 ft

http://www.bellgossett.com/productPages/Parts-Series-80.asp

Greenheck Cube 200-HP:

- Roof up-blast fan
- High pressure model
- Belt drive roof mounted
- 2,075 CFM

http://www.greenheck.com/pdf/fans/SeriesCCatalogJanuary2005.pdf

Lab Exhaust Fan:

- 100,000 CFM

York YCAV0247SA46:

- Chiller
- 225 nominal tons
- 287.3 kw/ton

APPENDIX P: Steep-Sloped Roof Preliminary Analysis

STEEP-SLOPED

Dead Load = Roof Material
= 90.25 lbs/ft

Live load = snow + wind
= 260.3 + 101.0
= 361.3 lbs/ft

$W_u = 1.4D$
$= 1.4(90.25)$
$= 126.35$ lbs/ft

$W_u = 1.2(90.25) + 1.6(361.3)$
$= 686.38$ lbs/ft

$$M_u = \frac{W_u L^2}{8} = \frac{(686.38)(44^2)}{8} = \frac{166103.96}{1000} = 166.1^{\prime k}$$

$\phi Z_x F_y \geq M_u$

$0.9 Z_x 50 \geq 166.1^{\prime k}$

$Z_x = 44.29 \text{ in}^3$

Try 14X30

$Z_x = 47.3 \text{ in}^3$

$W_u = 686.38 + 1.2(30)$
$= 722.38$ lbs/ft

$$M_u = \frac{722.38\,(44^2)}{8} = 174.8^{\prime k}$$

$\phi Z_x F_y \geq M_u$

$0.9(47.3)(50) \geq 174.8^{\prime k}$

$$\frac{2128.5}{12} \geq 174.8^{\prime k}$$

$177.4 \geq 174.8^{\prime k}$ ✓ $\boxed{W14 \times 30}$

APPENDIX Q: Low-Sloped Roof Preliminary Analysis

LOW-SLOPED

Dead load = roof material
= 90.25 lbs/ft

Live load = snow + wind
= 332.5 + 59.9
= 392.4 lbs/ft

$W_u = 1.4D$
$= 1.4(90.25)$
$= 126.35$ lbs/ft

$W_u = 1.2D + 1.6L$
$= 1.2(90.25) + 1.6(392.4)$
$= 736.14$ lbs/ft

$M_u = \frac{W_u L^2}{8} = \frac{(736.14)(37^2)}{8} = 119.3'^{k}$

$\phi Z_x F_y \geq M_u$

$Z_x = \frac{M_u}{\phi F_y} = \frac{119.3(12)}{(0.9)(50)} = 31.8\ in^3$

Try W14x22 $Z_x = 33.2 in^3$

$W_u = 736.14 + 1.2(22)$
$= 762.54$ lbs/ft

$M_u = \frac{762.54(37^2)}{8} = 130.5'^{k}$

$\phi Z_x F_y \geq M_u$

$\frac{0.9(33.2)(50)}{12} \geq 130.5'^{k}$

$124.5'^{k} \not\geq 130.5'^{k}$

$Z_x = \frac{130.5(12)}{(.9)(50)} = 34.8$

Try W12x26 $Z_x = 37.2$

$W_u = 736.14 + 1.2(26)$
$= 767.34$ lbs/ft

$M_u = \frac{(767.34 \text{ lbs/ft})(37^2)}{8} = 131.31^{k}$

$\phi Z_x F_y \geq M_u$

$\frac{0.9(37.2)(50)}{12} \geq 131.31^{k}$

$139.5^{k} \geq 131.31^{k}$ ✓ use $\boxed{W12 \times 26}$

APPENDIX R: Comparison of Preliminary Cost Analysis of Low and Steep-Sloped Roofs

	Unit Cost	Unit	Steep-Sloped Roof	Low-Sloped Roof
Brick	$ 400.00	M	$ 4,536.00	$ 12,120.00
Roofing Material	$ 93.50	square	$ 15,455.55	$ 13,005.85
Steel W 14x30	$ 31.50	LF	$ 45,517.50	-
Steel W 12x26	$ 27.00	LF	-	$ 38,340.00
		Totals	$ 65,509	$ 63,466

APPENDIX S: Summary of Option 1 Design Combinations

Combination	Number Tributary Widths	Member Trib Width (ft)	Roofing Material (lb/ft^2)	Dead Load (lbs/ft)	Snow Load (lbs/ft^2)	Live Load (lbs/ft)	Wind Load (lbs/ft^2)	Distributed Wind Load (lbs/ft)	Member L (ft)	Fy	Φ
1	10	18.80	1.40	26.4	27.3	513.2	5.5	103.4	44	50	0.9
2	11	17.09	1.40	24.0	27.3	466.6	5.5	94.0	44	50	0.9
3	12	15.67	1.40	22.0	27.3	427.7	5.5	86.2	44	50	0.9
4	13	14.46	1.40	20.3	27.3	394.8	5.5	79.5	44	50	0.9
5	14	13.43	1.40	18.8	27.3	366.6	5.5	73.9	44	50	0.9
6	15	12.53	1.40	17.6	27.3	342.2	5.5	68.9	44	50	0.9
7	16	11.75	1.40	16.5	27.3	320.8	5.5	64.6	44	50	0.9
8	17	11.06	1.40	15.5	27.3	301.9	5.5	60.8	44	50	0.9
9	18	10.44	1.40	14.7	27.3	285.1	5.5	57.4	44	50	0.9
10	19	9.89	1.40	13.9	27.3	270.1	5.5	54.4	44	50	0.9
11	20	9.40	1.40	13.2	27.3	256.6	5.5	51.7	44	50	0.9
12	25	7.52	1.40	10.6	27.3	205.3	5.5	41.4	44	50	0.9
13	30	6.27	1.40	8.8	27.3	171.1	5.5	34.5	44	50	0.9
14	35	5.37	1.40	7.6	27.3	146.6	5.5	29.5	44	50	0.9
15	40	4.70	1.40	6.6	27.3	128.3	5.5	25.9	44	50	0.9
16	45	4.18	1.40	5.9	27.3	114.1	5.5	23.0	44	50	0.9
17	50	3.76	1.40	5.3	27.3	102.6	5.5	20.7	44	50	0.9
18	55	3.42	1.40	4.8	27.3	93.3	5.5	18.8	44	50	0.9
19	60	3.13	1.40	4.4	27.3	85.5	5.5	17.2	44	50	0.9
20	65	2.89	1.40	4.1	27.3	79.0	5.5	15.9	44	50	0.9
21	70	2.69	1.40	3.8	27.3	73.3	5.5	14.8	44	50	0.9
22	75	2.51	1.40	3.6	27.3	68.4	5.5	13.8	44	50	0.9
23	80	2.35	1.40	3.3	27.3	64.2	5.5	12.9	44	50	0.9
24	85	2.21	1.40	3.1	27.3	60.4	5.5	12.2	44	50	0.9
25	90	2.09	1.40	3.0	27.3	57.0	5.5	11.5	44	50	0.9
26	95	1.98	1.40	2.8	27.3	54.0	5.5	10.9	44	50	0.9
27	100	1.88	1.40	2.7	27.3	51.3	5.5	10.3	44	50	0.9

Combination	Wu (lb/ft)	Mu (ftk)	Min Zx (in^3)	Trial Member Size	Nominal Weight	Trial Zx	Trial Wu (lb/ft)	Trial Mu (ftk)	ΦZxFy	Adequate Capacity? ΦZxFy>Trial Mu
1	935.6	226.4	60.4	W16x40	40.00	73.00	983.6	238.0	273.8	Yes
2	850.5	205.8	54.9	W18x35	35.00	66.50	892.5	216.0	249.4	Yes
3	779.7	188.7	50.3	W18x35	35.00	66.50	821.7	198.8	249.4	Yes
4	719.7	174.2	46.4	W16x31	31.00	54.00	756.9	183.2	202.5	Yes
5	668.2	161.7	43.1	W16x31	31.00	54.00	705.4	170.7	202.5	Yes
6	623.7	150.9	40.3	W14x30	30.00	47.30	659.7	159.7	177.4	Yes
7	584.7	141.5	37.7	W14x30	30.00	47.30	620.7	150.2	177.4	Yes
8	550.3	133.2	35.5	W14x26	26.00	40.20	581.5	140.7	150.8	Yes
9	519.8	125.8	33.5	W14x26	26.00	40.20	551.0	133.3	150.8	Yes
10	492.4	119.2	31.8	W12x26	26.00	37.20	523.6	126.7	139.5	Yes
11	467.8	113.2	30.2	W12x26	26.00	37.20	499.0	120.8	139.5	Yes
12	374.3	90.6	24.2	W12x22	22.00	29.30	400.7	97.0	109.9	Yes
13	311.9	75.5	20.1	W12x19	19.00	24.70	334.7	81.0	92.6	Yes
14	267.4	64.7	17.3	W12x16	16.00	20.10	286.6	69.4	75.4	Yes
15	233.9	56.6	15.1	W12x16	16.00	20.10	253.1	61.2	75.4	Yes
16	207.9	50.3	13.4	W12x16	16.00	20.10	227.1	55.0	75.4	Yes
17	187.1	45.3	12.1	W12x16	16.00	20.10	206.3	49.9	75.4	Yes
18	170.1	41.2	11.0	W12x16	16.00	20.10	189.3	45.8	75.4	Yes
19	155.9	37.7	10.1	W10x12	12.00	12.60	170.3	41.2	47.3	Yes
20	144.0	34.8	9.3	W10x12	12.00	12.60	158.4	38.3	47.3	Yes
21	133.7	32.4	8.6	W10x12	12.00	12.60	148.1	35.8	47.3	Yes
22	124.8	30.2	8.1	W10x12	12.00	12.60	139.2	33.7	47.3	Yes
23	116.9	28.3	7.5	W8x10	10.00	8.90	128.9	31.2	33.4	Yes
24	110.1	26.6	7.1	W8x10	10.00	8.90	122.1	29.5	33.4	Yes
25	104.0	25.2	6.7	W8x10	10.00	8.90	116.0	28.1	33.4	Yes
26	98.5	23.8	6.4	W8x10	10.00	8.90	110.5	26.7	33.4	Yes
27	93.6	22.7	6.0	W8x10	10.00	8.90	105.6	25.6	33.4	Yes

APPENDIX T: Cost of Option 1 Design Combinations

Combination	Member Size	Member Length	Number Tributary Widths	Tributary Width	Number of Beams	Total Linear Feet	Unit Cost (LF)	Total Cost
1	W16x40	44	10	18.8	11	968	$42.00	$40,656
2	W18x35	44	11	17.1	12	1056	$36.50	$38,544
3	W18x35	44	12	15.7	13	1144	$36.50	$41,756
4	W16x31	44	13	14.5	14	1232	$32.50	$40,040
5	W16x31	44	14	13.4	15	1320	$32.50	$42,900
6	W14x30	44	15	12.5	16	1408	$31.50	$44,352
7	W14x30	44	16	11.8	17	1496	$31.50	$47,124
8	W14x26	44	17	11.1	18	1584	$27.00	$42,768
9	W14x26	44	18	10.4	19	1672	$27.00	$45,144
10	W12x26	44	19	9.9	20	1760	$27.00	$47,520
11	W12x26	44	20	9.4	21	1848	$27.00	$49,896
12	W12x22	44	25	7.5	26	2288	$23.00	$52,624
13	W12x19	44	30	6.3	31	2728	$20.00	$54,560
14	W12x16	44	35	5.4	36	3168	$17.00	$53,856
15	W12x16	44	40	4.7	41	3608	$17.00	$61,336
16	W12x16	44	45	4.2	46	4048	$17.00	$68,816
17	W12x16	44	50	3.8	51	4488	$17.00	$76,296
18	W12x16	44	55	3.4	56	4928	$17.00	$83,776
19	W10x12	44	60	3.1	61	5368	$12.55	$67,368
20	W10x12	44	65	2.9	66	5808	$12.55	$72,890
21	W10x12	44	70	2.7	71	6248	$12.55	$78,412
22	W10x12	44	75	2.5	76	6688	$12.55	$83,934
23	W8x10	44	80	2.4	81	7128	$10.45	$74,488
24	W8x10	44	85	2.2	86	7568	$10.45	$79,086
25	W8x10	44	90	2.1	91	8008	$10.45	$83,684
26	W8x10	44	95	2.0	96	8448	$10.45	$88,282
27	W8x10	44	100	1.9	101	8888	$10.45	$92,880

APPENDIX U: Summary of Option 2 Design Combinations

Combination	Girder Tributary Width/Joist Length	Number of Girder Trib. Widths	Joist Tributary Width	Number Joist Tributary Widths	Roofing Material (lb/ft^2)	Joist type name	Joist Nominal Weight (lb/ft)	Dead Load along Joist (lbs/ft)
1	32	6	3.5	13	1.4	16K6	8.1	33.3
2	30	7	3.5	13	1.4	16K4	7.0	29.4
3	28	7	3.5	13	1.4	14K4	6.7	28.4
4	26	8	3.5	13	1.4	14K3	6.0	25.9
5	24	8	3.5	13	1.4	12K3	5.7	24.9
6	22	9	3.5	13	1.4	12K1	5.0	22.4
7	20	10	3.5	13	1.4	10K1	5.0	22.4
8	18	11	3.5	13	1.4	10K1	5.0	22.4
9	16	12	3.5	13	1.4	8K1	5.1	22.8
10	14	14	3.5	13	1.4	8K1	5.1	22.8
11	12	16	3.5	13	1.4	8K1	5.1	22.8
12	10	19	3.5	13	1.4	8K1	5.1	22.8
13	8	24	3.5	13	1.4	8K1	5.1	22.8

Combination	Snow Load (lbs/ft^2)	Live Load along Joist (lbs/ft)	Wind Load (lbs/ft^2)	Distributed Wind Load (lbs/ft)	Girder Length	Dead Load on Girder (lb/ft)	Live Load on Girder (lb/ft)	Distributed Wind Load on Girder (lb/ft)	Wu (lbs/ft)
1	27.3	95.6	5.5	19.3	44.0	118.86	873.60	176	1681.19
2	27.3	95.6	6.5	22.8	44.0	102.00	819.00	195	1588.80
3	27.3	95.6	7.5	26.3	44.0	92.80	764.40	210	1502.40
4	27.3	95.6	8.5	29.8	44.0	80.97	709.80	221	1409.65
5	27.3	95.6	9.5	33.3	44.0	72.69	655.20	228	1317.94
6	27.3	95.6	10.5	36.8	44.0	62.23	600.60	231	1220.43
7	27.3	95.6	11.5	40.3	44.0	56.57	546.00	230	1125.49
8	27.3	95.6	12.5	43.8	44.0	50.91	491.40	225	1027.34
9	27.3	95.6	13.5	47.3	44.0	45.71	436.80	216	926.54
10	27.3	95.6	14.5	50.8	44.0	40.00	382.20	203	821.92
11	27.3	95.6	15.5	54.3	44.0	34.29	327.60	186	714.10
12	27.3	95.6	16.5	57.8	44.0	28.57	273.00	165	603.09
13	27.3	95.6	17.5	61.3	44.0	22.86	218.40	140	488.87

Combination	Mu (lbs/ft)	GirderMin Zx (in^3)	Trial Girder Size	Girder Nominal Weight (lbs/ft)	Trial Zx	Trial Wu (lb/ft)	Trial Mu (ftk)	ΦZxFy	Adequate Beam Capacity? ΦZxFy>Trial Mu
1	406.85	108.5	W21x55	55	126	1747.2	422.8	472.5	Yes
2	384.49	102.5	W21x50	50	110	1648.8	399.0	412.5	Yes
3	363.58	97.0	W21x50	50	110	1562.4	378.1	412.5	Yes
4	341.13	91.0	W21x44	44	95.4	1462.4	353.9	357.8	Yes
5	318.94	85.1	W21x44	44	95.4	1370.7	331.7	357.8	Yes
6	295.35	78.8	W21x44	44	95.4	1273.2	308.1	357.8	Yes
7	272.37	72.6	W18x40	40	78.4	1173.5	284.0	294.0	Yes
8	248.62	66.3	W16x40	40	73	1075.3	260.2	273.8	Yes
9	224.22	59.8	W18x35	35	66.5	968.5	234.4	249.4	Yes
10	198.90	53.0	W18x35	35	66.5	863.9	209.1	249.4	Yes
11	172.81	46.1	W16x31	31	54	751.3	181.8	202.5	Yes
12	145.95	38.9	W14x30	30	47.3	639.1	154.7	177.4	Yes
13	118.31	31.5	W12x26	26	37.2	520.1	125.9	139.5	Yes

Combination	Plate Beam Tributary Width	Plate Beam Length	Dead Load on Plate Beam (lb/ft)	Live Load on Plate Beam (lb/ft)	Distributed Wind Load on Plate Beam (lb/ft)	Wu (lbs/ft)	Mu (lbs/ft)
1	44	31.33	239.05	1201.20	242	2402.38	294.83
2	44	31.33	222.93	1201.20	286	2418.24	296.77
3	44	31.33	224.40	1201.20	330	2455.20	301.31
4	44	31.33	211.49	1201.20	374	2474.91	303.73
5	44	31.33	213.92	1201.20	418	2513.03	308.40
6	44	31.33	212.46	1201.20	462	2546.47	312.51
7	44	31.33	212.46	1201.20	506	2581.67	316.83
8	44	31.33	222.23	1201.20	550	2628.60	322.59
9	44	31.33	221.96	1201.20	594	2663.48	326.87
10	44	31.33	235.71	1201.20	638	2715.18	333.21
11	44	31.33	239.38	1201.20	682	2754.78	338.07
12	44	31.33	257.71	1201.20	726	2811.98	345.09
13	44	31.33	268.71	1201.20	770	2860.38	351.03

Combination	Plate Beam Min Zx (in^3)	Trial Plate Beam Size	Plate Beam Nominal Weight (lbs/ft)	Trial Zx	Trial Wu (lb/ft)	Trial Mu (ftk)	ΦZxFy	Adequate Beam Capacity? ΦZxFy>Trial Mu
1	78.6	W21x44	44	95.4	2455.2	301.3	357.8	Yes
2	79.1	W21x44	44	95.4	2471.0	303.3	357.8	Yes
3	80.3	W21x44	44	95.4	2508.0	307.8	357.8	Yes
4	81.0	W21x44	44	95.4	2527.7	310.2	357.8	Yes
5	82.2	W21x44	44	95.4	2565.8	314.9	357.8	Yes
6	83.3	W21x44	44	95.4	2599.3	319.0	357.8	Yes
7	84.5	W21x44	44	95.4	2634.5	323.3	357.8	Yes
8	86.0	W21x44	44	95.4	2681.4	329.1	357.8	Yes
9	87.2	W21x44	44	95.4	2716.3	333.3	357.8	Yes
10	88.9	W21x44	44	95.4	2768.0	339.7	357.8	Yes
11	90.2	W21x44	44	95.4	2807.6	344.6	357.8	Yes
12	92.0	W21x44	44	95.4	2864.8	351.6	357.8	Yes
13	93.6	W21x44	44	95.4	2913.2	357.5	357.8	Yes

APPENDIX V: Cost of Option 2 Design Combinations

Combination	Joist Size	Total Joists Length (LF)	Unit Cost (LF)	Total Joist Cost	Girder Size	Girder Length	Girder Tributary Width	Number of Girders	Total Linear Feet	Unit Cost (LF)
1	16K6	4512	$5.75	$25,944.00	W21x55	44	32	10	440	$62.00
2	16K4	4512	$4.91	$22,153.92	W21x50	44	30	12	528	$56.50
3	14K4	4512	$4.57	$20,619.84	W21x50	44	28	14	616	$56.50
4	14K3	4512	$4.28	$19,311.36	W21x44	44	26	14	616	$49.50
5	12K3	4512	$4.06	$18,318.72	W21x44	44	24	14	616	$49.50
6	12K1	4512	$3.56	$16,062.72	W21x44	44	22	16	704	$49.50
7	10K1	4512	$3.56	$16,062.72	W18x40	44	20	18	792	$45.00
8	10K1	4512	$3.56	$16,062.72	W16x40	44	18	20	880	$45.00
9	8K1	4512	$3.63	$16,378.56	W18x35	44	16	22	968	$39.50
10	8K1	4512	$3.63	$16,378.56	W18x35	44	14	26	1144	$39.50
11	8K1	4512	$3.63	$16,378.56	W16x31	44	12	30	1320	$35.00
12	8K1	4512	$3.63	$16,378.56	W14x30	44	10	36	1584	$34.00
13	8K1	4512	$3.63	$16,378.56	W12x26	44	8	46	2024	$29.50

Combination	Total Girder Cost	Plate Beam Size	Total Linear Feet	Unit Cost	Total Plate Beam Cost	Area of Roof	Unit Cost of Roofing	Total Roofing material Cost	Total Cost
1	$27,280.00	W21x44	376	$49.50	$18,612.00	16544	$3.46	$57,242.24	$129,078.24
2	$29,832.00	W21x44	376	$49.50	$18,612.00	16544	$3.46	$57,242.24	$127,840.16
3	$34,804.00	W21x44	376	$49.50	$18,612.00	16544	$3.46	$57,242.24	$131,278.08
4	$30,492.00	W21x44	376	$49.50	$18,612.00	16544	$3.46	$57,242.24	$125,657.60
5	$30,492.00	W21x44	376	$49.50	$18,612.00	16544	$3.46	$57,242.24	$124,664.96
6	$34,848.00	W21x44	376	$49.50	$18,612.00	16544	$3.46	$57,242.24	$126,764.96
7	$35,640.00	W21x44	376	$49.50	$18,612.00	16544	$3.46	$57,242.24	$127,556.96
8	$39,600.00	W21x44	376	$49.50	$18,612.00	16544	$3.46	$57,242.24	$131,516.96
9	$38,236.00	W21x44	376	$49.50	$18,612.00	16544	$3.46	$57,242.24	$130,468.80
10	$45,188.00	W21x44	376	$49.50	$18,612.00	16544	$3.46	$57,242.24	$137,420.80
11	$46,200.00	W21x44	376	$49.50	$18,612.00	16544	$3.46	$57,242.24	$138,432.80
12	$53,856.00	W21x44	376	$49.50	$18,612.00	16544	$3.46	$57,242.24	$146,088.80
13	$59,708.00	W21x44	376	$49.50	$18,612.00	16544	$3.46	$57,242.24	$151,940.80

APPENDIX W: LEED Project Checklist

Project Checklist

Sustainable Sites — 14 Possible Points

Prereq 1	**Construction Activity Pollution Prevention**	Required
Credit 1	**Site Selection**	1
Credit 2	**Development Density & Community Connectivity**	1
Credit 3	**Brownfield Redevelopment**	1
Credit 4.1	**Alternative Transportation**, Public Transportation Access	1
Credit 4.2	**Alternative Transportation**, Bicycle Storage & Changing Rooms	1
Credit 4.3	**Alternative Transportation**, Low Emitting & Fuel Efficient Vehicles	1
Credit 4.4	**Alternative Transportation**, Parking Capacity	1
Credit 5.1	**Site Development**, Protect or Restore Habitat	1
Credit 5.2	**Site Development**, Maximize Open Space	1
Credit 6.1	**Stormwater Design**, Quantity Control	1
Credit 6.2	**Stormwater Design**, Quality Control	1
Credit 7.1	**Heat Island Effect**, Non-Roof	1
Credit 7.2	**Heat Island Effect**, Roof	1
Credit 8	**Light Pollution Reduction**	1

Water Efficiency — 5 Possible Points

Credit 1.1	**Water Efficient Landscaping**, Reduce by 50%	1
Credit 1.2	**Water Efficient Landscaping**, No Potable Use or No Irrigation	1
Credit 2	**Innovative Wastewater Technologies**	1
Credit 3.1	**Water Use Reduction**, 20% Reduction	1
Credit 3.2	**Water Use Reduction**, 30% Reduction	1

Energy & Atmosphere — 17 Possible Points

Prereq 1	**Fundamental Commissioning of the Building Energy Systems**	Required
Prereq 2	**Minimum Energy Performance**	Required
Prereq 3	**Fundamental Refrigerant Management**	Required
Credit 1	**Optimize Energy Performance**	1–10
Credit 2	**On-Site Renewable Energy**	1–3
Credit 3	**Enhanced Commissioning**	1
Credit 4	**Enhanced Refrigerant Management**	1
Credit 5	**Measurement & Verification**	1
Credit 6	**Green Power**	1

Materials & Resources — 13 Possible Points

Prereq 1	**Storage & Collection of Recyclables**	Required
Credit 1.1	**Building Reuse**, Maintain 75% of Existing Walls, Floors & Roof	1
Credit 1.2	**Building Reuse**, Maintain 95% of Existing Walls, Floors & Roof	1

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Credit 1.3	**Building Reuse**, Maintain 50% of Interior Non-Structural Elements	1
Credit 2.1	**Construction Waste Management**, Divert 50% from Disposal	1
Credit 2.2	**Construction Waste Management**, Divert 75% from Disposal	1
Credit 3.1	**Materials Reuse**, 5%	1
Credit 3.2	**Materials Reuse**, 10%	1
Credit 4.1	**Recycled Content**, 10% (post-consumer + 1/2 pre-consumer)	1
Credit 4.2	**Recycled Content**, 20% (post-consumer + 1/2 pre-consumer)	1
Credit 5.1	**Regional Materials**, 10% Extracted, Processed & Manufactured Regionally	1
Credit 5.2	**Regional Materials**, 20% Extracted, Processed & Manufactured Regionally	1
Credit 6	**Rapidly Renewable Materials**	1
Credit 7	**Certified Wood**	1

Indoor Environmental Quality 15 Possible Points

Prereq 1	**Minimum IAQ Performance**	Required
Prereq 2	**Environmental Tobacco Smoke (ETS) Control**	Required
Credit 1	**Outdoor Air Delivery Monitoring**	1
Credit 2	**Increased Ventilation**	1
Credit 3.1	**Construction IAQ Management Plan**, During Construction	1
Credit 3.2	**Construction IAQ Management Plan**, Before Occupancy	1
Credit 4.1	**Low-Emitting Materials**, Adhesives & Sealants	1
Credit 4.2	**Low-Emitting Materials**, Paints & Coatings	1
Credit 4.3	**Low-Emitting Materials**, Carpet Systems	1
Credit 4.4	**Low-Emitting Materials**, Composite Wood & Agrifiber Products	1
Credit 5	**Indoor Chemical & Pollutant Source Control**	1
Credit 6.1	**Controllability of Systems**, Lighting	1
Credit 6.2	**Controllability of Systems**, Thermal Comfort	1
Credit 7.1	**Thermal Comfort**, Design	1
Credit 7.2	**Thermal Comfort**, Verification	1
Credit 8.1	**Daylight & Views**, Daylight 75% of Spaces	1
Credit 8.2	**Daylight & Views**, Views for 90% of Spaces	1

Innovation & Design Process 5 Possible Points

Credit 1.1	**Innovation in Design**	1
Credit 1.2	**Innovation in Design**	1
Credit 1.3	**Innovation in Design**	1
Credit 1.4	**Innovation in Design**	1
Credit 2	**LEED Accredited Professional**	1

Project Totals 69 Possible Points

Certified 26–32 points Silver 33–38 points Gold 39–51 points Platinum 52–69 points

APPENDIX X: LEED Roof Heat Island Effect Criteria

SS Credit 7.2: Heat Island Effect: Roof
1 Point

Intent

Reduce heat islands (thermal gradient differences between developed and undeveloped areas) to minimize impact on microclimate and human and wildlife habitat.

Requirements

OPTION 1

Use roofing materials having a Solar Reflectance Index (SRI)[3] equal to or greater than the values in the table below for a minimum of 75% of the roof surface.
OR

OPTION 2

Install a vegetated roof for at least 50% of the roof area.

OR

OPTION 3

Install high albedo and vegetated roof surfaces that, in combination, meet the following criteria:

(Area of SRI Roof / 0.75) + (Area of vegetated roof / 0.5) >= Total Roof Area

Roof Type	**Slope**	**SRI**
Low-Sloped Roof	**≤ 2:12**	**78**
Steep-Sloped Roof	**> 2:12**	**29**

Potential Technologies & Strategies

Consider installing high-albedo and vegetated roofs to reduce heat absorption. SRI is calculated according to ASTM E 1980. Reflectance is measured according to ASTM E 903, ASTM E 1918, or ASTM C 1549. Emittance is measured according to ASTM E 408 or ASTM C 1371. Default values will be available in the LEED-NC v2.2 Reference Guide. Product information is available from the Cool Roof Rating Council website, at www.coolroofs.org.

APPENDIX Y: LEED Materials and Resources Criteria

Materials & Resources

MR Prerequisite 1: Storage & Collection of Recyclables
Required

Intent

Facilitate the reduction of waste generated by building occupants that is hauled to and disposed of in landfills.

Requirements

Provide an easily accessible area that serves the entire building and is dedicated to the collection and storage of non-hazardous materials for recycling, including (at a minimum) paper, corrugated cardboard, glass, plastics and metals.

Potential Technologies & Strategies

Coordinate the size and functionality of the recycling areas with the anticipated collection services for glass, plastic, office paper, newspaper, cardboard and organic wastes to maximize the effectiveness of the dedicated areas. Consider employing cardboard balers, aluminum can crushers, recycling chutes and collection bins at individual workstations to further enhance the recycling program.

MR Credit 1.1: Building Reuse: Maintain 75% of Existing Walls, Floors & Roof
1 Point

Intent

Extend the life cycle of existing building stock, conserve resources, retain cultural resources, reduce waste and reduce environmental impacts of new buildings as they relate to materials manufacturing and transport.

Requirements

Maintain at least 75% (based on surface area) of existing building structure (including structural floor and roof decking) and envelope (exterior skin and framing, excluding window assemblies and non-structural roofing material). Hazardous materials that are remediated as a part of the project scope shall be excluded from the calculation of the percentage maintained. If the project includes an addition to an existing building, this credit is not applicable if the square footage of the addition is more than 2 times the square footage of the existing building.

Potential Technologies & Strategies

Consider reuse of existing, previously occupied buildings, including structure, envelope and elements. Remove elements that pose contamination risk to building occupants and upgrade components that would improve energy and water efficiency such as windows, mechanical systems and plumbing fixtures.

MR Credit 1.2: Building Reuse – Maintain 95% of Existing Walls, Floors & Roof

1 Point in addition to MR Credit 1.1

Intent

Extend the life cycle of existing building stock, conserve resources, retain cultural resources, reduce waste and reduce environmental impacts of new buildings as they relate to materials manufacturing and transport.

Requirements

Maintain an additional 20% (95% total, based on surface area) of existing building structure (including structural floor and roof decking) and envelope (exterior skin and framing, excluding window assemblies and non-structural roofing material). Hazardous materials that are remediated as a part of the project scope shall be excluded from the calculation of the percentage maintained. If the project includes an addition to an existing building, this credit is not applicable if the square footage of the addition is more than 2 times the square footage of the existing building.

Potential Technologies & Strategies

Consider reuse of existing buildings, including structure, envelope and elements. Remove elements that pose contamination risk to building occupants and upgrade components that would improve energy and water efficiency such as windows, mechanical systems and plumbing fixtures.

MR Credit 1.3: Building Reuse: Maintain 50% of Interior Non-Structural Elements
1 Point

Intent

Extend the life cycle of existing building stock, conserve resources, retain cultural resources, reduce waste and reduce environmental impacts of new buildings as they relate to materials manufacturing and transport.

Requirements

Use existing interior non-structural elements (interior walls, doors, floor coverings and ceiling systems) in at least 50% (by area) of the completed building (including additions). If the project includes an addition to an existing building, this credit is not applicable if the square footage of the addition is more than 2 times the square footage of the existing building.

Potential Technologies & Strategies

Consider reuse of existing buildings, including structure, envelope and interior non-structural elements. Remove elements that pose contamination risk to building occupants and upgrade components that would improve energy and water efficiency, such as mechanical systems and plumbing fixtures. Quantify the extent of building reuse.

MR Credit 2.1: Construction Waste Management: Divert 50% From Disposal
1 Point

Intent

Divert construction, demolition and land-clearing debris from disposal in landfills and incinerators. Redirect recyclable recovered resources back to the manufacturing process. Redirect reusable materials to appropriate sites.

Requirements

Recycle and/or salvage at least 50% of non-hazardous construction and demolition debris. Develop and implement a construction waste management plan that, at a minimum, identifies the materials to be diverted from disposal and whether the materials will be sorted on-site or co-mingled. Excavated soil and land-clearing debris do not contribute to this credit. Calculations can be done by weight or volume, but must be consistent throughout.

Potential Technologies & Strategies

Establish goals for diversion from disposal in landfills and incinerators and adopt a construction waste management plan to achieve these goals. Consider recycling cardboard, metal, brick, acoustical tile, concrete, plastic, clean wood, glass, gypsum wallboard, carpet and insulation. Designate a specific area(s) on the construction site for segregated or comingled collection of recyclable materials, and track recycling efforts throughout the construction process. Identify construction haulers and recyclers to handle the designated materials. Note that diversion may include donation of materials to charitable organizations and salvage of materials on-site.

MR Credit 2.2: Construction Waste Management: Divert 75% From Disposal
1 Point in addition to MR Credit 2.1

Intent

Divert construction and demolition debris from disposal in landfills and incinerators. Redirect recyclable recovered resources back to the manufacturing process. Redirect reusable materials to appropriate sites.

Requirements

Recycle and/or salvage an additional 25% beyond MR Credit 2.1 (75% total) of non-hazardous construction and demolition debris. Excavated soil and land-clearing debris do not contribute to this credit. Calculations can be done by weight or volume, but must be consistent throughout.

Potential Technologies & Strategies

Establish goals for diversion from disposal in landfills and incinerators and adopt a construction waste management plan to achieve these goals. Consider recycling cardboard, metal, brick, acoustical tile, concrete, plastic, clean wood, glass, gypsum wallboard, carpet and insulation. Designate a specific area(s) on the construction site for segregated or commingled collection of recyclable materials, and track recycling efforts throughout the construction process. Identify construction haulers and recyclers to handle the designated materials. Note that diversion may include donation of materials to charitable organizations and salvage of materials on-site.

MR Credit 3.1: Materials Reuse: 5%
1 Point

Intent

Reuse building materials and products in order to reduce demand for virgin materials and to reduce waste, thereby reducing impacts associated with the extraction and processing of virgin resources.

Requirements

Use salvaged, refurbished or reused materials such that the sum of these materials constitutes at least 5%, based on cost, of the total value of materials on the project.

Mechanical, electrical and plumbing components and specialty items such as elevators and equipment shall not be included in this calculation. Only include materials permanently installed in the project. Furniture may be included, providing it is included consistently in MR Credits 3–7.

Potential Technologies & Strategies

Identify opportunities to incorporate salvaged materials into building design and research potential material suppliers. Consider salvaged materials such as beams and posts, flooring, paneling, doors and frames, cabinetry and furniture, brick and decorative items.

MR Credit 3.2: Materials Reuse: 10%
1 Point in addition to MR Credit 3.1

Intent

Reuse building materials and products in order to reduce demand for virgin materials and to reduce waste, thereby reducing impacts associated with the extraction and processing of virgin resources.

Requirements

Use salvaged, refurbished or reused materials for an additional 5% beyond MR Credit 3.1 (10% total, based on cost).

Mechanical, electrical and plumbing components and specialty items such as elevators and equipment shall not be included in this calculation. Only include materials permanently installed in the project. Furniture may be included, providing it is included consistently in MR Credits 3–7.

Potential Technologies & Strategies

Identify opportunities to incorporate salvaged materials into building design and research potential material suppliers. Consider salvaged materials such as beams and posts, flooring, paneling, doors and frames, cabinetry and furniture, brick and decorative items.

MR Credit 4.1: Recycled Content: 10% (post-consumer + 1/2 pre-consumer)
1 Point

Intent

Increase demand for building products that incorporate recycled content materials, thereby reducing impacts resulting from extraction and processing of virgin materials.

Requirements

Use materials with recycled content such that the sum of post-consumer recycled content plus one-half of the pre-consumer content constitutes at least 10% (based on cost) of the total value of the materials in the project.

The recycled content value of a material assembly shall be determined by weight. The recycled fraction of the assembly is then multiplied by the cost of assembly to determine the recycled content value.

Mechanical, electrical and plumbing components and specialty items such as elevators shall not be included in this calculation. Only include materials permanently installed in the project. Furniture may be included, providing it is included consistently in MR Credits 3–7.

Recycled content shall be defined in accordance with the International Organization of Standards document, *ISO 14021—Environmental labels and declarations—Self-declared environmental claims (Type II environmental labeling).*

Post-consumer material is defined as waste material generated by households or by commercial, industrial and institutional facilities in their role as end-users of the product, which can no longer be used for its intended purpose.

Pre-consumer material is defined as material diverted from the waste stream during the manufacturing process. Excluded is reutilization of materials such as rework, regrind or scrap generated in a process and capable of being reclaimed within the same process that generated it.

Potential Technologies & Strategies

Establish a project goal for recycled content materials and identify material suppliers that can achieve this goal. During construction, ensure that the specified recycled content materials are installed. Consider a range of environmental, economic and performance attributes when selecting products and materials.

MR Credit 4.2: Recycled Content: 20% (post-consumer + 1/2 pre-consumer)

1 Point in addition to MR Credit 4.1

Intent

Increase demand for building products that incorporate recycled content materials, thereby reducing the impacts resulting from extraction and processing of virgin materials.

Requirements

Use materials with recycled content such that the sum of post-consumer recycled content plus one-half of the pre-consumer content constitutes an additional 10% beyond MR Credit 4.1 (total of 20%, based on cost) of the total value of the materials in the project.

The recycled content value of a material assembly shall be determined by weight. The recycled fraction of the assembly is then multiplied by the cost of assembly to determine the recycled content value.

Mechanical, electrical and plumbing components and specialty items such as elevators shall not be included in this calculation. Only include materials permanently installed in the project. Furniture may be included, providing it is included consistently in MR Credits 3–7.

Recycled content shall be defined in accordance with the International Organization of Standards document, *ISO 14021—Environmental labels and declarations—Self-declared environmental claims (Type II environmental labeling)*.

Post-consumer material is defined as waste material generated by households or by commercial, industrial and institutional facilities in their role as end-users of the product, which can no longer be used for its intended purpose.

Pre-consumer material is defined as material diverted from the waste stream during the manufacturing process. Excluded is reutilization of materials such as rework, regrind or scrap generated in a process and capable of being reclaimed within the same process that generated it.

Potential Technologies & Strategies

Establish a project goal for recycled content materials and identify material suppliers that can achieve this goal. During construction, ensure that the specified recycled content materials are installed. Consider a range of environmental, economic and performance attributes when selecting products and materials.

MR Credit 5.1: Regional Materials: 10% Extracted, Processed & Manufactured Regionally
1 Point

Intent

Increase demand for building materials and products that are extracted and manufactured within the region, thereby supporting the use of indigenous resources and reducing the environmental impacts resulting from transportation.

Requirements

Use building materials or products that have been extracted, harvested or recovered, as well as manufactured, within 500 miles of the project site for a minimum of 10% (based on cost) of the total materials value. If only a fraction of a product or material is extracted/harvested/recovered and manufactured locally, then only that percentage (by weight) shall contribute to the regional value.

Mechanical, electrical and plumbing components and specialty items such as elevators and equipment shall not be included in this calculation. Only include materials permanently installed in the project. Furniture may be included, providing it is included consistently in MR Credits 3–7.

Potential Technologies & Strategies

Establish a project goal for locally sourced materials, and identify materials and material suppliers that can achieve this goal. During construction, ensure that the specified local materials are installed and quantify the total percentage of local materials installed. Consider a range of environmental, economic and performance attributes when selecting products and materials.

MR Credit 5.2: Regional Materials: 20% Extracted, Processed & Manufactured Regionally

1 Point in addition to MR Credit 5.1

Intent

Increase demand for building materials and products that are extracted and manufactured within the region, thereby supporting the use of indigenous resources and reducing the environmental impacts resulting from transportation.

Requirements

Use building materials or products that have been extracted, harvested or recovered, as well as manufactured, within 500 miles of the project site for an additional 10% beyond MR Credit 5.1 (total of 20%, based on cost) of the total materials value. If only a fraction of the material is extracted/harvested/recovered and manufactured locally, then only that percentage (by weight) shall contribute to the regional value.

Potential Technologies & Strategies

Establish a project goal for locally sourced materials and identify materials and material suppliers that can achieve this goal. During construction, ensure that the specified local materials are installed. Consider a range of environmental, economic and performance attributes when selecting products and materials.

MR Credit 6: Rapidly Renewable Materials

1 Point

Intent

Reduce the use and depletion of finite raw materials and long-cycle renewable materials by replacing them with rapidly renewable materials.

Requirements

Use rapidly renewable building materials and products (made from plants that are typically harvested within a ten-year cycle or shorter) for 2.5% of the total value of all building materials and products used in the project, based on cost.

Potential Technologies & Strategies

Establish a project goal for rapidly renewable materials and identify products and suppliers that can support achievement of this goal. Consider materials such as bamboo, wool, cotton insulation, agrifiber, linoleum, wheatboard, strawboard and cork. During construction, ensure that the specified renewable materials are installed.

MR Credit 6: Rapidly Renewable Materials
1 Point

Intent

Reduce the use and depletion of finite raw materials and long-cycle renewable materials by replacing them with rapidly renewable materials.

Requirements

Use rapidly renewable building materials and products (made from plants that are typically harvested within a ten-year cycle or shorter) for 2.5% of the total value of all building materials and products used in the project, based on cost.

Potential Technologies & Strategies

Establish a project goal for rapidly renewable materials and identify products and suppliers that can support achievement of this goal. Consider materials such as bamboo, wool, cotton insulation, agrifiber, linoleum, wheatboard, strawboard and cork. During construction, ensure that the specified renewable materials are installed.

APPENDIX Z: Cost Estimate Backup Sheets

Concrete			
Floor	Thickness of Slab (ft)	Area with Concrete Slab (ft^2)	Volume (ft^3)
Basement	0.42	1012	422
Floor 1	0.42	14642	6101
Floor 2	0.54	14642	7931
Floor 3	0.54	14642	7931
Floor 4	0.54	14642	7931
Roof	0.54	14642	7931
		Total (ft^3)	**38247**
		Total (cy)	**1417**

WWF	
Floor	Area with WWF (ft^2)
Basement	1012
Floor 1	14642
Floor 2	14642
Floor 3	14642
Floor 4	14642
Roof	14642
Total (ft^2)	**74222**

Steel Columns			
Size	Total LF	Unit Cost (LF)	Totals
W14x109	822	$ 123.00	$ 101,106.00
W14x159	74	$ 180.00	$ 13,320.00
W14x193	543	$ 220.00	$ 119,460.00
W12x65	78	$ 73.50	$ 5,733.00
W12x53	173	$ 60.00	$ 10,380.00
W12x79	163	$ 88.50	$ 14,425.50
W12x58	66	$ 65.00	$ 4,290.00
W14x145	19	$ 164.00	$ 3,116.00
		Total Column Cost	**$ 271,830.50**

Steel Decking	
Floor	Area with Decking (ft^2)
Basement	0
Floor 1	0
Floor 2	14642
Floor 3	14642
Floor 4	14642
Roof	14642
Total (ft^2)	**58568**

Steel Beams							
Size	**Total LF**	**Unit Cost**	**Totals**	**Size**	**Total LF**	**Unit Cost**	**Totals**
First Floor				**Fourth Floor**			
W14x22	110	$ 25.00	$ 2,750.00	W10x12	7	$ 13.55	$ 94.85
W21x50	31	$ 56.50	$ 1,751.50	W12x14	23	$ 15.80	$ 363.40
W12x19	12	$ 23.50	$ 282.00	W12x16	12	$ 17.50	$ 210.00
W12x14	12	$ 15.80	$ 189.60	W12x19	328	$ 23.50	$ 7,708.00
Floor 1 Total			$ 4,973.10	W16x26	66	$ 29.50	$ 1,947.00
Second Floor				W18x35	1529	$ 39.50	$ 60,395.50
W10x12	9	$ 13.55	$ 121.95	W18x50	46	$ 56.50	$ 2,599.00
W12x14	27	$ 15.80	$ 426.60	W21x44	23	$ 49.50	$ 1,138.50
W12x19	303	$ 23.50	$ 7,120.50	W21x50	215	$ 56.50	$ 12,147.50
W16x26	54	$ 29.50	$ 1,593.00	W24x117	49	$ 132.00	$ 6,468.00
W16x31	31	$ 35.00	$ 1,085.00	W24x68	430	$ 76.50	$ 32,895.00
W16x89	300	$100.00	$ 30,000.00	W24x68	207	$ 76.50	$ 15,835.50
W18x35	1488	$ 39.50	$ 58,776.00	W8x10	69	$ 11.30	$ 779.70
W18x40	88	$ 45.00	$ 3,960.00	Floor 4 Total			$142,581.95
W18x50	46	$ 56.50	$ 2,599.00	**Roof**			
W21x50	146	$ 56.50	$ 8,249.00	C6x8.2	15	$4.87	$74.71
W24x117	11	$132.00	$ 1,452.00	W10x12	13	$13.55	$172.90
W24x162	65	$185.00	$ 12,025.00	W12x14	19	$15.80	$302.73
W24x94	520	$106.00	$ 55,120.00	W12x16	12	$17.50	$210.00
W8x10	90	$ 11.30	$ 1,017.00	W12x19	324	$23.50	$7,618.00
Floor 2 Total			$183,545.05	W14x22	31	$25.00	$766.50
Third Floor				W16x26	67	$29.50	$1,972.67
W10x12	8	$ 13.55	$ 108.40	W16x31	274	$35.00	$9,580.20
W12x16	12	$ 17.50	$ 210.00	W18x35	1,334	$39.50	$52,680.36
W12x19	332	$ 23.50	$ 7,802.00	W18x40	23	$45.00	$1,020.15
W12x44	24	$ 49.50	$ 1,188.00	W21x44	23	$49.50	$1,138.50
W16x26	66	$ 29.50	$ 1,947.00	W24x55	744	$62.00	$46,149.08
W18x35	1499	$ 39.50	$ 59,210.50	W24x94	49	$106.00	$5,230.04
W18x50	46	$ 56.50	$ 2,599.00	W8x10	200	$11.30	$2,260.00
W21x44	23	$ 49.50	$ 1,138.50	Roof Total			$129,175.82
W21x50	184	$ 56.50	$ 10,396.00				
W24x117	49	$132.00	$ 6,468.00			**Total Beam Cost**	**$600,910**
W24x68	637	$ 76.50	$ 48,730.50				
W8x10	74	$ 11.30	$ 836.20				
Floor 3 Total			$140,634.10				

Insulation				
Interior Walls - Acoustic Batt Insulation				
		Insulation Thickness (in)		
	Wall Height (ft)	Wall Length (ft)		
		6"	3.5"	None
Basement	8	-	24	83
1st Floor	9	29	160	284
2nd Floor	9	219	908	147
3rd Floor	9	286	609	130
4th Floor	9	147	823	133
	Total Insulation per Thickness	**6129 SF**	**22692 SF**	

Exterior Walls - 2" Rigid Insulation	
	Wall Surface Area (SF)
Basement	761 SF
1st Floor	2004 SF
2nd Floor	2045 SF
3rd Floor	1977 SF
4th Floor	1977 SF
Roof	0 SF
Total Wall Insulation	**8764 SF**

Floor - 2" Rigid Insulation	
	Floor Surface Area (SF)
Basement	0 SF
1st Floor	0 SF
2nd Floor	0 SF
3rd Floor	0 SF
4th Floor	0 SF
Roof	14642 SF
Total Floor Insulation	**14642 SF**

Masonry						
Face Brick						
	Total Surface Area	Area of Openings	Area of Brick	Number of Bricks*		Mortar**
South Elevation	10067.25	3321.25	6746	44187		
West Elevation	2726	843.75	1882.25	12329		
North Elevation	5412.36	1237.5	4174.86	27346		
East Elevation	2882.04	787.5	2094.54	13720		
			Total Brick (EA)	97582		
			Total Bricks (M)	**98**	**Total Mortar (CF)**	**843**
1/2" Recess Alternative Brick						
	Total Surface Area	Area of Openings	Area of Brick	Number of Bricks*		Mortar**
South Elevation	653.94	131.94	522	3420		
West Elevation	232	12	220	1441		
North Elevation	763.3112	84	679.3112	4450		
East Elevation	84.5	0	84.5	554		
			Total Bricks (EA)	9865		
			Total Bricks (M)	**10**	**Total Mortar (CF)**	**86**

*Assumed Running Bond

**8.6 CF per 1000 bricks

APPENDIX AA: Consigli Owner's Meetings Minutes

Consigli Owner's Meeting Minutes
September 18, 2006

Schedule

- Steve J. provided a schedule update on several items, especially the 2nd floor
- Building enclosure
    - WPI and WBDC have concerns, would like to see enclosure by end of September
    - Consigli says it will be enclosed by end of October
- Casework
    - Brent A. had concerns about humidity
    - Consigli says it should stay between 30-60% humidity and they have a way to monitor it
    - For the most part, humidity has been ok but recently it went up to 70% for a day
    - Brent A. has additional concerns that doors, etc. will operate correctly after building is occupied and today's high temperatures and the possibility of dew collecting inside the building
- VanZelm
    - Brent A. is concerned that they feel as if they have been "thrown under the bus"
    - Steve H. agreed that this is probably the case
    - Brent/Consigli discussed that this is partially due to some miscommunication
- WPI employees are asking for a panic button inside temp. controlled rooms
- Ice Machines
    - John McDermott pointed out that these ice machines and other changes to scope need to be identified as such
    - There have been some issues with design changes that have been written off as RFIs
- Keying
    - Consigli will need to meet with WPI to discuss their needs

Consigli Owner's Meeting Minutes
September 25, 2006

Credit for light fixtures
- WPI fit out had temporary lighting
- Changed to permanent
- Type D & F fixtures – 1 hour for fixture, charged 1 ½ hours

Glass should be in South East wall by Friday or Monday

WPI needs handicapped access buttons
- Will get specs for them

National Grid came on Friday to energize transformer
- 1 more week to permanent power

Mechanical panels going in

Putting ceilings in lab first and then putting in case work
- Experimented with opposite way

Building inspector coming on Wednesday to look at the above ceiling fire protection

Billing should go to "New Gate Properties LLC" at the WPI address
- Attention Jeff Solomon

Accident
- Lost a couple of hours work
- Man went to the hospital to get stitches

Automatic light shut off system
- Wont be able to see the screen that displays that the lights are going out with current installation plan
- Will get a sample to see

Consigli Owner's Meeting Minutes
October 2, 2006

- Design changes discussion
    - Blast wall is an eye sore – ivy, trellis, and brick topics discussed
    - Landscape – Value engineering effects
    - Elevator card swipe
    - Fume hoods changes
    - Emergency power to water chillers if power goes out
- 2 Week Delivery Delays
    - Glass
    - Screening
    - Air/AC Units
- Construction
    - Humidity level in building ok
    - Air temperature constant
    - Water proofing delayed because of rain
    - VanZelm response testing on windows, curtain wall, and metal panels
- Discussion to potentially plant grass on MRI roof
- Detailed discussion and update of the previous weeks minutes
    - VanZelm response
    - Task light switch selection to be visible from work areas
    - Keying
    - 2nd floor – seal cracks before sealer is put on
    - Landscaping
    - Retaining Wall at entrance alternatives
        - Symmetry one wall on either side
        - Single wall – no symmetry
        - Brick
        - Retaining wall versa lock
    - Café Marketing, heating, etc
    - RFI - Location of Ice Machine MEP hookups are needed
- Work Bench surface confirmed

Consigli Owner's Meeting Minutes
October 9, 2006

Water Drainage:
- Perforated pipe for water drainage
- Will need detail soon

Pressure testing the walls

Cracks in the concrete:
- Concrete mixture may have been too wet

Consigli Owner's Meeting Minutes
October 16, 2006

Schedule

- Building is completely closed in except for some cosmetic pieces of the curtain wall
- They are finishing the MRI roof
    - A couple leaks were discovered along the edge
- They will pressure test the exterior waterproofing later this week
- There's a crane coming on the 24th
    - Will this cause workspace issues?
- Temporary doors have to stay in place in one location in order to get the rest of the casework into the building
- Paving may begin this week
    - Materials will be stacked in the north parking lot
    - This might case more work space issues with the crane

VanZelm

- Old issue: not receiving reports from them about the space above the ceiling
    - Consigli had been asking for a "punch list" instead of what they really needed
    - The theory is that VanZelm has been looking above the ceiling, they just haven't sent the reports

Sprinkler Heads

- NFPA 13 code interpretation
    - They want the engineer to specifically approve an alternative sprinkler head, not just say that "it's ok as long as it meets the code"

Plumbing Inspector

- Gas shut-offs
    - In the labs, need to be near the hoods
    - The issue is whether or not the shut-offs are "accessible" enough

Concrete Floor

- Hollowness issue
    - Some areas of hollowness near cracks
    - Some owners and Consigli will do a walk-through to double check that the hollowness is not excessive, although the guy who tested it said it was ok

Diesel Tank

- A guy with the fire department wants them to put a permanent jersey barrier in front of the tank in order to prevent a car from driving into it, even though there is so much space between the tank and the traveled way that this seems ridiculous
- Will try an alternative – maybe install bollocks?

Consigli Owner's Meeting Minutes
October 25, 2006

- Bench Location Discussion
- Change Request for racks signed by John Miller
- 2nd floor fume hoods come in today
- Lights in lab space
- Current Progress:
    - Fume hoods
    - Catering space in dining area
    - Lights coordinated
- Punchlist Schedule
    - MEP - December 7th
    - Basement issues to be worked out in field (location of utilities)
- Enclosing Building: Most done by end of fall
- VanZelm Responses
    - Waiting on inspection report
    - Sketches for labs (Fermentation lab)
    - Ice machine Drains
- Keying: which rooms are to have Separate Keying
- Generator: Received permit – Spacing Units: 5ft
- Underlayment: Crack Fix: Still in progress samples in use
    - Still Looking for company to present a solution
    - Specrete Xterior Rock: No Epoxy (too expensive)

Consigli Owner's Meeting Minutes
November 13, 2006

Roofing:
- Roofing inspection in late November

MEP Coordination
- MEP coordination is done
- Subs signed off

Gas Valve Shut Offs:
- Inspector came and said they were fine

Keying:
- Some disagreements about what rooms would be keyed
- By the end of the month, they will have decided on the level of control for all doors

Casework:
- Consigli and the casework supplier, Gibson, have had similar humidity readings
- Gibson is comfortable with the readings
- The warranty is still pending

Landscaping
- Waiting on hardscaping

MRI:
- Have not decided on how to finish MRI walls

Lighting:
- Spacing the outdoor lights 30 feet apart

Consigli Owner's Meeting Minutes
November 20, 2006

Schedule

- Started VCT on 4th floor
- Tile on 3rd floor is next, then back to 4th floor for finishes
- Ceilings are going in on 2nd floor
- Screen wall to be finished this week if good weather

VanZelm

- Nothing from VanZelm in 2 weeks, need the following from them:
  - Info about the cooler in the tel/data room in the basement
  - Sketches from fermentation
  - Incorrectly routed exhaust duct
- Issue with bus duct being either over designed or poorly designed – VanZelm's fault?

Casework

- Humidity – Consigli received verbal "ok" about the indoor conditions from the manufacturer, still waiting on written documentation

Seminar Room Seating

- Column cover and platform need to be installed ASAP so that seating can be based off of accurate interior dimensions

Flashing and crack fillings

- 3rd and 4th floor are done
- The sub will be back in a couple weeks to finish

Café

- The area has been leased and the tenant will do a design

Freight Elevator

- The dimensions in the shop drawing were off
- Solutions:
  - Get a smaller elevator
    - $9000 and 2 weeks to get it
  - Do a lot of work to fix it
    - $10000
  - This is a contingency item

Consigli Owner's Meeting Minutes
November 27, 2006

- Keying: Still Deciding
- Freight Elevator: Smaller Basket to replace construction Basket
  - Save hydraulic lift but Capacity Dropped from 5000 to 4500, Shouldn't the capacity go up?
- Masonry: Spruce Green cornice on exterior landscape
- Punchlist: MEP for roof screen
- Detail of Connection of New Floor with Drywall: Floor replaces old cracked floor

Consigli Owner's Meeting Minutes
December 4, 2006

Interior Finishes:

- Carpet coming in next week for the 4th floor of the existing building
- Hanging dry wall in basement
- Nothing new with the humidity concerning the casework

VanZelm Issues:

- Need to approve five gallon heaters

Water Leak:

- There was a water leak during wall testing
- Think it is a problem with the window and gasket

Elevator:

- Want the elevator to be 5,000lbs capacity

Mail

- Concern over how they will get mail into the building once it is open

Consigli Owner's Meeting Minutes
December 11, 2006

- Discussion of Budget
    - Walkways- Masonry Going to Cost twice the original estimate
        - Fill in cracks – entrance to café
        - 9000-31000 big jump: Some things were over looked
        - Craig was upset
    - Sprinkler heads in basement
        - 30 to cover depth – efficient?
        - Heat is required because of the sprinklers
- Curtain wall Caps & Panels 100%
- Freight elevator: New parts in January
- Carpet: installation on certain floors
    - Issue with construction next to finished areas
    - Keep those areas blocked off
    - Lock doors
- VanZelm Response: Behind the 8 ball
    - RFI's, Difficult to get Response
- Staging Begins in Seminar Room
- Last Piece of Parking Garage Thurs @ 11:30 Ceremony
- Freight elevator 4500 lbs: State Regulations
    - No matter what the strength of the lift, it's regulated by the size of the cage
    - Test for 5000 lbs & see if that works just for future reference

Consigli Owner's Meeting Minutes
January 22, 2007

VanZelm Issues:

- Trying to determine if they are doing extra work or doing work that was left out of the plans

Roof Units:

- York came to work on roof units 1 and 2

Elevator:

- All pieces are parts are in for the elevator

Interior Finishes:

- Beginning painting the first floor of the new building
- Aluminum rail in the lobby should be in by the end of the month

Plant Lab:

- Changes ordered

Underlayment on 68 Prescott St:

- Northwest is done except for the 4th floor
- Consigli thinks there was a bad mark, says it is not Northwest's fault
- Chipped out the extra concrete and will be repouring it

Numbering of the Building:

- The building needs a new number because it cannot stay 60-68 Prescott St.
- Will apply to the city to get a number

Consigli Owner's Meeting Minutes
January 29, 2007

- Milestones:
    - 1/15: Final Paint 4th Floor
    - 1/17: Ceiling Grid 1st Floor
    - 1/18: Doors & Windows 4th Floor
    - 1/18: Complete Final Paint 3rd Floor
    - 1/18: Complete Ceiling Grid Basement
    - 1/29: Complete Ceiling Grid 1st Floor
    - 1/31: Complete Final Paint 2nd Floor
    - 2/2: Punchlist 4th Floor
- 2hr Fire Doors – Not getting label for Fire Protection because of holes due to Keycard access
    - Possible Solution: Electric Hinges
- Thoughts on Dividing Café Area to separate from 24/7 area
- Emergency Power Capacity: Issue with Transformer to service system
    - Does the transformer service the whole building or just a single floor?
- Stairwell: Rail Should meet code after conversion

APPENDIX AB: Interview with Judith Nitsch

Judith Nitsch, WPI Class of ’89, Member of WPI Board of Trustees
Phone Conference Minutes
November 11, 2006

Reasons for LEED policy at WPI

- Bartlett Center
  - Extra challenging because design did not begin with LEED in mind
  - Worked toward achieving certification by using alternative mechanical equipment that cost more initially but will be paid off in 4 to 7 years, depending on oil prices
- New dorm: they started with LEED in mind so certification should not be difficult to achieve
- Benefits: there is a “huge marketing benefit to the USGBC medallion” and WPI wants to send the message that they care about the environment

Information from a green building presentation by Judith Nitsch

- Reasons to go “green”:
  - Operational savings
  - Marketing
  - Environmental Consciousness
- Examples of benefits:
  - Hospital rooms: average recovery time reduced from 4 days to 3 days in a “green” room
  - Retail: going green has increased sales by 10%
  - Schools: learning is increased in green buildings
  - Offices: production rates increased so much that additional costs to go green were offset

Green Policies on College Campuses

- Many college have different budgets for capital and operations, therefore, the same party the has to front the capital doesn’t always accrue the benefits and this presents a challenge in the initial funding of LEED projects
- Colleges that “compete” with WPI already have significant environmental policies in place